INTERRELATIONS OF THE FOSSIL FUELS

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PREFACE.

When this study was taken up, the writer planned to present a synopsis of geological observations, then to summarize results obtained from investigation of chemical relations of the fossil fuels and finally to discuss the problems involved. Illness, beginning in October, 1917, interrupted the study and no attempt to resume it was made until the summer of 1919. But the labor of reducing bulky abstracts to brief digests and of filling gaps in the accumulated material became increasingly difficult, so that within a few months, it became certain that the work could not be completed by the writer, who, being well advanced in his 80th year, could not hope that youthful vigor will return. He has prepared a table of contents and an index, which may render the portion, already published, more nearly available for those interested in the study.

The War made communication with continental Europe very uncertain during the time when preparation of abstracts of publications on Paleozoic coals were in course of preparation, so that there was little opportunity to consult Professors Barrois, Dannenberg Petrascheck, v. Ammon and other geologists, who had always been prompt in replying to my too numerous letters of inquiry, which must have tried their patience. My indebtedness to American geologists is very great; they have not hesitated to give me access even to unpublished material. It may seem invidious to make special mention of any, but failure to recognize my obligations to Doctor David White and Professor Willis T. Lee would be inexcusable. I must make grateful acknowledgment of the unvarying and generous courtesy extended by Doctor I. Minis Hays, Secretary of the American Philosophical Society, and Professor R. A. F. Penrose, Jr., chairman of the publication committee.

TABLE OF CONTENTS.

The references are to the lower pagination.

Prefatory note 1
Peat
Condition requisite for accumulation 3
Extent of peat deposits 11
Peat-forming plants 13
Classification of peat 16
Growth of peat deposits 18
Lebertorf or Sapropel stage 22
Succeeding stages vary 27
Structures and constituents of peat deposits 29
Preservation of vegetable matter in bogs 36
Effect of pressure upon peat 38
Preservation of peat deposits 41
Bursting bogs 55
Floor or mur of peat deposits 56
Roof or toit 61
Soils of vegetation 63
Resistance to erosion 68
Contemporaneous erosion 71
Some chemical features of peat 72
Composition 78
Distillation products of peat 85
Summary 87
Tertiary coals 99
Classification 102
Pliocene coals 104
Miocene coals 106
Oligocene coals 116
Eocene coals 130
Some chemical features of Tertiary coals 152
Summary 170

Cretaceous coals
England 185
France 186
Hanover 187
Silesia 191
Bohemia 191
Moravia 192
Lower Austria 192
Hungary 193
Borneo 194
Queensland 194
New Zealand 196
Greenland 199
North America 200
Laramie 204
Fox Hills 213
Pierre 218
Colorado 244
Dakota 251
Kootenai 252
Some chemical features of Cretaceous coals 257
Summary 268
Jurassic coals 285
Great Britain 285
France 291
Austria 292
Hungary 294
Spitzbergen 298
Siberia 298
New Zealand 300
Alaska 300
Jura-Triassic coals 301
Queeensland 301
New South Wales 304
Triassic coals 304
Great Britain 304

Sweden 305
France 305
Germany 307
Austria 308
Hungary 310
United States 310
Mexico 318
Some chemical features 319
Summary 327
Paleozoic coals
Australia 334
Queensland 334
New South Wales 336
India 341
Siberia 348
Russia in Europe 350
Spitzbergen 353
Upper Silesia 354
Lower Silesia and Bohemia 360
Hungary 366
Bohemia 367
Saxony 374
Thuringer Wald 380
Saarbrück field 381
Ruhr Basin 386
Aachen basins 389
Belgium and Northern France 390
France 398
Rock fragments in coal 400
Erect stems 402
Central plateau of France 405
Commentry 410
Autun 413
Bretagne 415
Spain 416
South Wales 420

South Staffordshire 423
North Staffordshire 425
Lancashire 426
Yorkshire 429
Lothians 433
Brazil 436

ERRATA.

Page 25, l. 13, for Faulsclam read Faulschlamm.
Page 118, l. 22, for t othe read to the.
Page 128, l. 13, for Schrotter read Schrötter.
Page 141, l. 16, for Beckly read Beekly.
Footnote, for Beckley read Beekly.
Page 142, l. 12, for Beckly read Beekly.
Page 193, l. 14, for Schrotter read Schrötter.
Page 214, l. 2, for with read within.
Page 355, l. 3, for Dennenberg read Dannenberg.
Page 359, l. 12 from bottom, for Stigamaria read Stigmaria.
Page 389, l. 10 from bottom, for Measurers read Measures.
Page 399, l. 4, for elast read least.

INTERRELATIONS OF THE FOSSIL FUELS.

I.

By JOHN J. STEVENSON.

(*Read April 14, 1916.*)

Peat and the Tertiary Coals.

Prefatory Note.—In an earlier treatise,[1] the writer considered some problems bearing upon the accumulation of coal in beds. Other, but closely related, problems will be considered here in the effort to ascertain how closely the fossil fuels, aside from petroleum, are related to each other in their physical and chemical characteristics as well as in their mode of accumulation. In preparing for these studies, the writer has travelled scores of thousands of miles in foreign regions to secure information respecting disputed localities and, in this land, he has made examinations in almost all of the coal-producing states. But life is short and distances are great; a man can gather little by direct study; to secure the knowledge necessary for intelligent discussion of the subject, he must collect and compare, as far as possible, the observations reported by others. This has been attempted; several thousands of reports, notes, memoirs and monographs have been read and the abstracts have been digested, in so far as they contained matter bearing on the problems in hand. All citations, except where otherwise stated, are at first hand.

Some may regard study after this fashion as wasted force, especially because the matters involved appear to possess little of economic interest; but the labor has been performed without compulsion and with no hope of reward, except that of criticism by

[1] "The Formation of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 1–116, 519–643; Vol. LI., pp. 423–553; Vol. LII., pp. 31–162.

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those who may regard the work as defective and the conclusions as unsound. The study has been made solely to find solutions of problems which had perplexed the writer during more than 45 years. The results are presented, not because they are final, but in the belief that those students who take up the investigation anew at some future time, when knowledge shall have been increased, will find their labor lessened by this opening of by-paths in the literature; and equally in the hope that credit may be restored to some of the earlier students, whose work has been forgotten or ignored.

The autochthonous origin of coal is taken for granted in this work; argument in favor of that doctrine has been presented in the writer's "Formation of Coal Beds."

The various terms applied to fossil fuels have, in a general way, sufficiently definite significance. When one hears the words peat, brown coal, coal, anthracite, he recognizes each as referring to a substance with which he is familiar. Museums contain specimens from many localities, properly labeled, so that the names become for students thoroughly definitive. Tables of comparative analyses are given in textbooks, which mark off the limits of the several substances with ample distinctness. It is true that in most textbooks and in most lecture courses there is proper though somewhat incidental statement that the specimens represent, for the most part, what may be termed typical forms, and that from each type in each direction to the next the transition is practically imperceptible. Yet that that conception lacks concreteness, the more so because each appears to be characteristic of a certain stage in the earth's history. But the names are those of groups, each comprised of members differing greatly in chemical and physical features; and there are strange overlappings, for in the groups less advanced chemically, one finds substances very similar to some in the more advanced, while in the latter he occasionally meets with forms almost indistinguishable from some of the former.

Since the extent of chemical change, as a rule, increases with the age of the deposit, it is most convenient to consider the fuels in the order of their occurrence in time.

Peat.

Peat is the familiar accumulation of more or less changed vegetable matter observed in localities sufficiently moist. It is most abundant in Pleistocene and Recent deposits, but a very similar material occurs in the Tertiary and, even in the Carboniferous, one finds a substance, which in hand specimens can hardly be distinguished from well-dried peat.

Conditions Requisite for Accumulation.—As asserted long ago by Alex. Brongniart, constant supply of moisture in considerable quantity is a prerequisite for growth of peat. Ponds and shallow lakes in glacial drift have been favorite localities in the northern part of the temperate zone, where deposits vary in extent from a few square rods to several scores of square miles. Areas of deep water are made shallow by accumulating animal and vegetable remains, largely of humble types, and eventually become filled with normal peat. But such deposits are, individually, of small extent, though they are so numerous that, collectively, they cover much of the formerly glaciated surface within North America and Europe. Peat areas of greatest extent are those originating on coastal plains or on those bordering rivers, where the sluggish drainage is checked readily by petty obstacles and small patches of swamp become united until a great space has been occupied. Some deposits of this type have an area of many hundreds of square miles.

Peat has provided fuel for much of northern Europe during centuries and the literature with reference to it is voluminous; but it has no economic importance within the tropics, so that definite statements respecting its occurrence are comparatively few. Explorers naturally were concerned more with geography and anthropology, so that one finds usually little aside from incidental statements to the effect that a region is swampy, boggy and difficult to traverse. But more than one hundred years ago, Jameson[2] stated that Anderson had received peat from Sumatra. Certainly the conception that true peat is confined to the temperate zones is erroneous. Livingstone in 1858 and 1866 presented abundant evi-

[2] R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151–153.

dence of its existence in equatorial Africa. Wall and Sawkins in 1860 found peaty deposits on the island of Trinidad, which even after desiccation at 300° F. contained 35 per cent. of organic matter. In 1870, Hartt reported his discovery of peat in the state of São Salvador, S.L. 10°, as well as in the state of São Paulo, both in Brazil. Brown described peaty deposits in the Demarara region; "from Santa Rosa on through the Staboots, the head of the Barabara River, there are many tracts of open land, composed of black bog-mud formed by decayed vegetables and covered with a growth of rank sedges and rushes." Some portions of these "savannas" are permanent swamps, in which the Ita palm, *Mauritia flexuosa,* is one of the prominent trees, rising to the height of 60 feet. Harrison, in discussing the same region, says that peat occurs in many of the low-lying coast lands, where it is from 1 to 10 feet thick, though usually not exceeding 4 feet. Considerable portions of this "pegass" land are covered with the Aeta palm.[3]

Long ago, Lyell described the general features of the Dismal Swamp and of the cypress swamps of the lower Mississippi River, both of which were discussed in detail by Shaler at a later date. Kuntze[4] in 1895 described the vast wooded swamp, a mass of peat extending for 3 degrees of latitude along the Lourenço River of Brazil. The conditions in Florida, where the peat areas are great and the deposits often very thick, have been described in detail by Harper, and several observers have made note of the peat in Bermuda. Livingstone, Cameron, Lugard and Miss Kingsley have presented proof that peat is abundant in equatorial Africa.[5]

During the progress of the Dutch explorations in Sumatra, 1891, Koorders observed a great Flachmoor covered with a 30-meters-high mixed forest growing on peat, which Larive's measurements

[3] G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63; C. F. Hartt, "Geology and Physical Geography of Brazil," Boston, 1870, pp. 365, 509; C. B. Brown, "Physical, Descriptive and Economic Geology of British Guiana," Geol. Survey, London, 1875, pp. 34, 91; J. F. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.,* Vol. LXIII., 1907, p. 292.

[4] O. Kuntze, "Geogenetische Beiträge," Leipzic, 1895, pp. 67, 68.

[5] For detailed statement of these observations in tropical and subtropical regions, see "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.,* Vol. L., 1911, pp. 565–573.

proved to be 9 feet thick. Examination, microscopical and chemical, showed that this peat has structure and composition wholly similar to the peat of Europe, though the plants from which it is derived are different.[6]

Molengraaff[7] studied central Borneo in 1893–94. On many pages he notes the presence of marshes along the larger rivers and describes them as boggy. These marshes in many cases are densely wooded though frequently covered with water during several months in succession. A considerable deposit of peat was seen near the Tebaoeng River. In ascending Babas Hantoe, one of the Madi mountains, he reached, at 500 meters above the sea, an extensive plateau, on which the forest contains many conifers, these increasing upward until at 700 meters they were paramount. There a soft soil had been reached, mosses had appeared and the character throughout was that of a forested swamp. The deeply trodden narrow path wound among wet spongy cushions covered with moss until at 1,000 meters the area was a genuine morass and advance could be made only by leaping from the root of one tree to that of another. The altitude is not sufficient to remove the locality from tropical conditions, as this is almost directly under the equator. On the other side of the mountain, he descended into a valley, which at first showed patches of marshy forest with peat. Farther down, the peat patches became continuous and he soon recognized that the whole of this valley and probably the whole Madi plateau are covered with a marshy forest, standing in a thick layer of peat, which consists of the half decayed remains of all kinds of trees, shrubs and mosses, a true tropical peat bog; but, like tropical fens generally, it is composed chiefly of remains of trees, thus contrasting with fens of temperate zones, which originate so frequently from mosses and a limited variety of shrubs. The yellow-brown fen water from this peat area flows into the Tebaoeng River.

Koorders, as cited by Potonié, reported that, in old Javan and

[6] H. Potonié, "Die Enstehung der Steinkohle und der Kaustobiolithe überhaupt," 5te Aufl., 1910, pp. 152–160.

[7] G. A. F. Molengraaff, "Geological Explorations in Central Borneo, 1893–94," Leiden, 1902, pp. 83, 84, 307, 310. The citations are from the edition in English; the edition in Dutch was published in 1899.

Sumatran forests, where hard woods grow, fallen trees are numerous, which though decades old are still in condition good enough for export. Molengraaff gives an illustration more remarkable, because the conditions are not constant. The Lake district of the Upper Kappewas River is merely the overflow area during flood time. The lakes contract during the dry season, leaving only shallow channelways in which fish accumulate. The Malays gather in camps to harvest the fish and the camp fires frequently spread, causing great destruction in the forest. In one portion of this district, a great "submerged" forest remains, composed of medium-sized charred stumps, in varying stages of decay and all broken off at approximately the same height. A sprinkling of younger trees was seen, but owing to the unfavorable conditions—flooding and fires—the forest cannot recover. This locality was described by Ida Pfeiffer in 1846, when the features differed little from those observed by Molengraaff, almost half a century later. Evidently, decay of rooted stumps may be as slow under the equator as in temperate regions.

Wichmann[8] gathered available information respecting peat deposits in the Indian archipelago, summarizing observations by Junghuhn, Koorders, Molengraaff, Machielson, Schwaner, Teyssmann, Van Nouhys and himself. The largest fen in Java is in Samarang; about 2,500 hectares have been brought under cultivation but not less than 1,500 still remain as swamp. Borings at one locality show that the peat is from 30 to 31 meters thick and "peat islands" have risen in it at various times. The Javan peat is an inferior fuel as it contains much ash; that from Kapogan has 27 per cent.

Very many swamps within the east coast residency of Sumatra have been drained and placed under cultivation; but much still remains untouched. A great fenland of 80,000 hectares, between the Siak and Kampar rivers, has been known long time and it has been described by Koorders, botanist to the Ijzerman expedition of 1891. As Wichmann presents the matter, peat is evidently a commonplace in Sumatra. He refers to Molengraaff's observations in central Borneo. W. J. M. Machielson found fens along several rivers in another portion and C. A. L. M. Schwaner reported them from

[8] C. E. A. Wichmann, "The Fens of the Indian Archipelago," *K. Akad. Wetensch.*, Amsterdam, Vol. XII., 1909, pp. 70–74.

several localities in the south and east divisions, where all the streams are blackwater. Some of the Borneo peat is very good, that collected by J. W. Van Nouhys containing only 4.58 per cent. of ash.

A very great part of the fenland in the Archipelago has been drained and converted into rice, sugar cane or tobacco plantations, but Wichmann estimates that the area of existing fens exceeds 1,000,000 hectares or more than 3,800 square miles. The uniformity of climatal conditions prevents the variations observed in fens of colder regions. The structure, in Wichmann's opinion, resembles that seen in the Coal Measures, where roots of *Lepidodendron* and *Sigillaria* are found in the floor of coal beds; so in the tropical fens, the trees are rooted in the subjacent clay. As accumulation of peat does not choke the trees rapidly, these frequently remain erect in the peat.

It would seem to be sufficiently evident that a hot climate offers no hindrance to the accumulation of peat, if only the conditions exist which are required for that accumulation in a cool climate.

Even a very severe climate does not prevent the growth of peat. Nathorst[9] visited the Renntier-tal of Spitzbergen in 1882 and saw there, resting on the river débris, 0.25 meter of clayey peat underlying 2 meters of peat: he cites Gunnar Andersson as stating that the upper division consists chiefly of brown moss, but that some layers are crowded with leaves of *Salix polaris*. Nathorst found a leaf of *Salix reticulata* in the underlying impure peat. Andersson believes that peat-formation has ceased in Spitzbergen and that the deposits are relics of a less cold period. Be that as it may, there can be no doubt that bogs are numerous, though in many instances they are thin. The writer in 1904 found enough peat on both sides of Advent bay, N.L. 78°, to make walking not too attractive and there was living vegetation on the surface in many places. A. E. Stevenson reported that the black mud is more than knee-deep for considerable distances along the shore of Icefiord to more than 12 miles south from below Advent bay. Peat was seen on Bell sound.

[9] A. G. Nathorst, "Beiträge zur Geologie der Bären Insel, Spitzbergen, und des König-Karl. Landes," *Bull. Geol. Inst. Univ. Upsala*, Vol. X., 1910, p. 403.

Russell[10] has described conditions on the tundra and in the interior of Alaska. He says that "without exaggeration, it may be stated that the whole of Alaska, excepting the steepest rock slopes and the tops of high mountains, is covered with a dense carpet of moss." The reported thickness of peat on the tundra is from 2 to 150 even to 300 feet. The peat is growing, though the depth to frozen material is only from 8 to 14 inches. Capps[11] has described an Alaskan peat deposit, exposed in a bluff for more than a mile. The peat, 39 feet thick and resting on unconsolidated glacial till, is fibrous, with abundant stumps and roots, but probably consists mostly of *Sphagnum*. The mass is divided at 7 feet from the top by 2 feet of white volcanic ash. The surface beyond the edge of the bluff is covered with a thick coat of *Sphagnum* and supports a dense forest of spruce with little undergrowth. The peat, ash and till are permanently frozen at a few inches back from the edge of the bluff, though that is subjected to the long hours of summer sunshine. Even the surface is frozen at a depth of 6 inches in early July.

The arrangement of roots shown by spruce trees growing at the edge of the bluff as well as by the stumps, which compose a great part of the deposit, is wholly unlike that ordinarily observed. Spruce growing on solid ground, frozen or not, has radial roots, parallel with the surface and penetrating only a few inches; but, at this White River locality, the roots of trees growing on the edge of the bluff and those of stumps buried at different levels in the peaty mass have a very different arrangement. Instead of a single, flat-based set of radial roots, these trees all show a central stem, often several feet long, from which roots branch off at irregular intervals, with an upper set of roots near the surface, corresponding to those of the normal tree. Investigation proved that roots below the frost-line are still undecayed, though they differ in color from the uppermost set of radial roots and evidently are no longer active. Capps reached the conclusion that, in each case, the seedling spruce, having established itself on the mossy soil, sent out the normal radial roots; but

[10] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125, 126, 129.

[11] S. R. Capps, "An Estimate of the Age of the last great Glaciation in Alaska," *Journ. Washington Acad.*, Vol. V., 1915, pp. 108–115.

the rapidly thickening moss and consequent rising plane of frozen ground cut off nutriment from the existing roots, necessitating the formation of a newer set nearer the surface. He measured one tree, which had 24 inches of vegetable matter above the lowest horizontal roots. At 6 feet above the surface it had 373 annual rings, so that the growth of the peaty mass had been at the rate of one foot in about 200 years. One foot of the compact peat lower down represents a much longer period.

Tyrrell[12] has studied peat deposits in a great part of Canada. He notes that in northern Canada the peat, 10 to 12 feet thick, often rests on a plate of clear ice. The water for this came from springs below the permanently frozen ground and it favored the growth of peat mosses in summer. The peat of Canada, except in the southern portion, consists practically of undecomposed moss from top to bottom, as the intense cold prevents change, the lower portions being frozen. In the Klondike region, the moss layer is rarely more than 5 or 6 feet thick, but there may be below it a variable mass of "muck," a mixture of sand and vegetable matter, the latter not from mosses. This muck he thinks originated in part as vegetable mould which has slidden down into the narrow valleys. It may contain about 30 per cent. of plant material.

Cochrane,[13] who crossed Siberia long ago, was more interested in the people, the roads and the weather than in geology, but he has given some notes respecting localities in eastern Siberia, where his progress was impeded. On the return journey from Nishney Kolymsk, N.L. 69°, E.L. 160°, southwestwardly to Okotsk, N.L. 60°, E.L. 142°, he travelled over a region of mostly overflowed meadows, alder country and "marshy swamps"; the last part of the distance, 7 days' journey, is a continuous swamp covered, at times, with fallen trees. Between Okotsk and Yakutsk, N.L. 62°, the route from the Okota River passes for long distances across wooded swamps; for 50 miles east from the Aldan River, the region is a

[12] J. B. Tyrrell, "Crystophenes or Buried Sheets of Ice in the Tundra of Northern America," *Journ. of Geology*, Vol. 12, 1904, pp. 232–236; also letter of August 3, 1915.

[13] J. D. Cochrane, "Narrative of a Pedestrian Journey through Russia and Siberian Tartary," Amer. ed., Phila., 1824, pp. 220, 225, 234, 238, 319, 325, 342.

most dreary, swampy plain, the road being a wooden causeway in the latter half of the distance. Forty miles of swamp were encountered in the 80 miles east from the Lena River. Cochrane thinks that Siberia is an impregnable province, as, owing to the vast extent of the swamps, a few hours of work would render any one of the roads impassable.

Atkinson[14] has given some information respecting western Siberia between Ekatherineburg and Tomsk. In going from Omsk to Kainsk, a distance of about 200 miles, he crossed much swampy area, continuous at one time for 31 miles. There are many lakes south from Kainsk in an area of 150 by 40 miles, all of them surrounded by broad belts of reeds. Morass prevails between the lakes as well as for nearly 100 miles farther southward.

Nordenskiold's[15] references to peat are merely incidental. His studies were along the coast and excursions into the interior were, for the greater part, comparatively short. The plain on the Yalmal peninsula, west from the mouth of the Yenisei, is tundra-like, full of marshes and streams; on Taimur land farther west, the plains are covered with a continuous, very green vegetation, a mixture of grasses and allied plants with mosses and lichens. In the Gyda peninsula, where Schmidt obtained remains of Mammoth in 1866, N.L. 70°, the stratum containing the remains rests on marine clay and is covered with sands alternating with beds of decayed plant material, completely corresponding with peat deposits formed in lakes of the tundra. The description of the Chukch peninsula, in northeast Siberia, is very similar to that given by Cochrane.

Incidental references in a description by the Comité géologique of Russia[16] give some conception of the marsh-covered area on both sides of the Transsiberian railway. The Steppe de Baraba, between the Irtych and the Ob, about 10 degrees of longitude, is described as differing from steppes at the west in that it has many great marshes

[14] T. W. Atkinson, "Oriental and Western Siberia," New York, 1858, pp. 151, 153, 156.

[15] A. E. Nordenskiold, "The Voyage of the Vega," New York, 1882, pp. 154, 253, 309, 422.

[16] "Aperçu des explorations géologiques et minières le long du Transsiberien," Publié par le Comité Géologique de Russie, 1900, pp. 4, 52, 63, 113.

and forests of birch and aspen. Beyond the Ob, the road passes for about 50 miles through a marshy forest of pines and firs, which extends from near Tomsk southward for more than 300 miles almost to the head of the Kia River. In the area west from Lake Baikal, within the drainage area of the Yenisei, there are impassable marshes of vast extent, sometimes forested—the Taiga. This condition exists between the Kau and Oka Rivers and northward to the Angara. Beyond Lake Baikal, broad valleys hold great marshes covered with vegetation throughout and conifers are abundant in such localities. East from the Yablonovy mountains, the Taiga is characteristic of moist area; pines, firs and black birches are the common forms.

True peat is present in localities where the required conditions appear to be wanting. The so-called forest peat has accumulated to a thickness of several feet in many places within the Rocky Mountain region, the material being merely offal from dense forests of giant firs. In northern New England, one often sees the surface in railroad cuts more or less covered with moss-peat, though the rock is a gravelly sand. This is wholly similar to the Rohhumus, seen so commonly on rock surfaces within forests of both Europe and North America. But the needed conditions are here, though not sufficient to encourage rapid growth. The offal from the trees is abundant and retentive of water, while the moss, once saturated, parts very slowly with its moisture.

Extent of Peat Deposits.—As already stated, a peat deposit may cover only a few square feet or it may cover an area of hundreds even thousands of square miles. The subtropical Everglades of Florida embrace not far from 7,000 square miles; the partly living, partly buried peat of Holland, Belgium and north France has nearly as great extent, as shown by Lorié. Russell's exploration of Alaska led him to assert that peat covers not only the vast tundra but also most of the wooded region as well as of the river plains. The buried deposit of the Ganges delta has been found in numerous borings within a space of more than 2,500 square miles. Skertchly has shown that in the Fenland of England the peat is practically continuous throughout 1,800 square miles.[17] Great areas exist on the north

[17] R. M. Harper, "Preliminary Report on Peat Deposits of Florida," 1910; J. Lorié, "Les dunes intérieures, les tourbières basses et les oscillations du

German border some of which are comparable to the English Fenland. In the majority of the cases cited, accumulation occurred on coastal plains, but the great rivers of Alaska, Sumatra, Paraguay, Brazil and other lands flow amid vast plains, which are peat covered in much of their extent.

The total area, within which peat has been accumulating since the Quaternary began, probably exceeds that in which similar deposits accumulated during any prior period of similar duration. That is not to say that contemporaneous deposits were at any time continuous throughout the area; they were not and they are not, any more than brown coal or stone coal was continuous throughout the regions in which rocks of the respective ages are found. One must always bear in mind that the great deposits of peat did not begin at the same time throughout their present extent. It is altogether probable for all, as it is certain for many, that originally they were small separated patches, beginning in favorable localities and becoming united by transgression. This process is not confined to low-lying areas; Lorié[18] has proved its importance in the Hochmoors of Holland. If conditions favoring growth were checked, the individual deposits would remain isolated.

Growing peat offers great resistance to erosion, as is well-known to those who are familiar with conditions on streams which are subject to violent floods. But where the accumulation is on a permeable yielding material, it may be floated off after long continued flooding. A good illustration has been given by Carpenter,[19] who, in describing a ride through the Panama canal, says that on Gatun lake he found floating islands, tropical swamps lifted from their foundations by the rising water, some of them several acres in extent. Other notes by this author may be given here, though

sol," *Arch. Mus. Teyler*, II., Vol. III., 1890, pp. 424-437; I. C. Russell, "Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, p. 129; C. Lyell, "Antiquity of Man," 1871, pp. 336, 337; W. T. Blanford, "A Manual of the Geology of India," 1879, p. 400; S. B. J. Skertchly, "The Geology of the Fenland," Mem. Geol. Surv. of Great Britain, 1877.

[18] J. Lorié, "Les hautes tourbières au nord du Rhin," *Arch. Mus. Teyler*, II., Vol. IV., 1893, p. 169.

[19] F. G. Carpenter, "Steaming through the Canal," *Los Angeles Times*, January 10, 1914.

they concern matters to be considered on another page. He was surprised by the abundance of floating and aquatic plants. Already, within the few weeks of the lake's existence, great beds of water lettuce and of water hyacinth had covered much of the surface and were associated with extensive patches of green scum. The water hyacinth had become a pest. The destruction of forests had been rapid; non-water-loving trees were killed by gradual rise of the water-level, but palms showed great power of endurance. Frequently one of the latter is seen with its trunk completely submerged and only the crown of leaves showing above, resembling a bunch of gigantic ferns on the surface.

But when dried by exposure to light and air peat is unstable material. Change in direction of drainage may deprive a considerable area of the needed moisture and growth will be stopped. Unless the surface be invaded by trees, running water will break continuity of the bog and that will be ruptured into "hags," of which Scottish writers have given vivid descriptions. In a moist climate, this process of destruction is slow, as is seen in much of England and Scotland, because peat absorbs moisture and retains it with great tenacity. It may well be that growth may be checked or wholly stopped in one portion of an area while it continues in another, as in the Fenland of England, where peat still grows in one district, though the general climatic change has caused cessation elsewhere. If untoward conditions continue, the peaty cover becomes desiccated and is removed by the wind or other agencies—a fact which is unpleasantly familiar to those who have cultivated drained peat bogs.

Peat-forming Plants.—Peat, being merely vegetable material undergoing chemical change with greater or less exclusion of oxygen, may be the product of any group of plants. The popular belief, based on surface study of bogs in northern Europe, has always been that mosses are the chief source of material for peat; and this no doubt led to the conception that no true peat is to be found within the tropics, since neither *Sphagnum* nor *Hypnum* prospers amid tropical conditions. Yet more than 100 years ago

Alex. Brongniart[20] announced that peats, consisting wholly of leaves, had been observed in Holland and that similar deposits, formed of leaves from resinous trees, occur in the Jura. There are very many peat deposits without *Sphagnum.* It and other mosses occur rarely in the peats of Florida and it seems to be wanting in the Kampar-Siak area of Java. Molengraaff asserts that mosses contribute little to the peats of central Borneo. C. A. Davis has shown that *Sphagnum* is a comparatively late comer into the Michigan peats and that it is still absent at a great proportion of the localities. Even in northern Europe, many observers have made it clear that mosses are only a few of the peat-forming plants; and in the older deposits there are thick benches in which *Sphagnum* is almost or altogether wanting. But mosses are all-important in arctic and sub-arctic deposits of this day, while they are comparatively unimportant in those of the temperate and sub-tropical as well as tropical areas.

Sedges appear to have been the most important peat producers in much of the north temperate zone; but a peat deposit is not the product of any single plant or group of plants, though this is not to deny the existence of such deposits, for they do occur under exceptional conditions. In the southern part of the United States, one finds conifers and deciduous trees making the chief contributions; the condition is evidently the same in central Borneo, where according to Molengraaff, the peat consists almost wholly of remains of trees, and Koorders makes a similar remark respecting Java. Any plant, apparently, may become a peat-maker; the hyacinth, introduced into Florida, where it threatened to ruin the navigable rivers, has become a peat-producer of no little importance. Certain members of the palm family contribute to the peat deposits of Florida and it appears altogether probable that, when the peats of the Amazon, Orinoco and Paraguay have been studied, palms will be found among the most important of the contributing plants.

It is well known that the sedge-association, in advancing from the shore of a lake or pond, is very apt to form a floating mat. One

[20] Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, T. II., p. 41.

finds this shown in the Sudd of the Upper Nile. Willey[21] speaks of that as the serious obstacle to navigation between Khartoum and Gondokoo. The principal interruption is 25 miles long and within 150 miles there are three others aggregating 60 miles. The growth is very rapid after an unusually high flood in the upper rivers, which brings down much vegetation and sediment; but if the rainy season be short, the growth is checked and the current carries out the young plants, not yet strong enough to resist. The top in the older denser areas is so dry that it can be burned, but the mass is so matted that it must be cut with saws and the pieces dragged away. This Sudd consists mostly of water-papyrus and a bamboo, known as elephant grass, with a convolvulus creeping over all. Besides this *in situ* material is more or less of transported stuff. One would imagine that this last would be in comparatively small proportion on the lower sections as most of it would be stopped by the first raft.

Wright[22] cites Willcox to the effect that the Sudd interferes seriously with the river's flow. It causes division into numerous streams, which lose themselves, north from Lado, N.L. 6°, in the extensive swamps; Willcox suggested that the channel could be opened by dredging and could be kept open by planting willows on the banks, which would enable the strong current to prevent closing. The absence of willows along the banks makes control of the swamps impossible. Wright cites also Lord Cromer, who notes Major Peake's discovery that the Sudd is not simply a tangle of vegetation floating on the water, but is a mass of decayed vegetation, papyrus roots and earth, much like peat in consistence and so compressed by the current that at places elephants can cross it safely. According to Willey, the thickness is only a few feet in the overflowed swampy area but increases abruptly to 15 and 20 feet in the channel. The close resemblance to the floating mat of more familiar types of sedges is evident. Were it not for the rapid current underneath, the whole channel would soon be filled by the more or less decayed material from the under side of the mat. But

[21] D. A. Willey, "The Barrage of the Nile," *Nat. Geog. Mag.*, Vol. XXI., 1910, pp. 174, 184.

[22] G. F. Wright, "Scientific Confirmations of Old Testament History," Oberlin, 1906, pp. 74-77.

these currents, even in great flood, are powerless against the mat; the river at some places is diverted into a false channel but at others it passes through a series of shallow lakes.

The groups of higher plants, contributing to production of peat, are for the most part those which prefer a soil containing organic acids formed during decomposition of vegetable matter. Some of them are provided with root modifications, enabling them to grow even when rooted in water-covered peat. Others, the ordinary conifers and deciduous trees of swamp areas, have no such modifications and grow only on the less moist portions. In case the water-level rise permanently so as to prevent aeration of the roots, the trees die; but mere accumulation of peat about the roots is not the direct cause of death, as it is proved abundantly by the existence of mighty trees in the western forests, the intervals between them showing several feet of peaty accumulation, in which young firs and scrubby oaks have grown from the seed. The great *Taxodium* and *Nyssa* are rooted directly in the water-covered peat, but aeration is secured by means of the "knees" and the arched roots which rise above the water surface. Aeration is as necessary to these trees as to the others and they can be drowned quite as easily as the junipers. Lowly forms of plant life make, as a rule, merely incidental contributions to peat, but under certain conditions they may accumulate in mass. Some forms of fresh water algæ are constituents of organic muds in pools or ponds, which so often become the foundation for peat, while occasionally one finds a layer of diatomaceous earth in or over the peat.

Classification of Peat.—The great economic importance of peat in some German states led early to close study of that material in all its phases and, of course, to classification, a differentation of the varieties of peat and of the types of deposits. This work had been done in great part by the diggers before scientific students began, so that in all efforts at classification one finds greater or less use made of the popular terms. Zirkel[23] offered a grouping based on the character of the original materials;

Moostorf, derived from water-loving mosses, chiefly *Sphagnum,*

[23] F. Zirkel, "Lehrbuch der Petrographie," Bonn, 1866, Vol. I., p. 398.

Conferventorf, from free-swimming plants, Conferva, Naiads, etc.,
Haidetorf, heath-peat from various heaths, largely *Erica tetralix,*
Holztorf, mostly from mouldered stems of trees,
Meertorf, from seaweeds, is of rare occurrence.

No one of these forms, except very rarely, is found as the mass of a bog, but all may be seen in the vertical section of a single deposit, indicating variations in conditions during growth. Zirkel gives also the ordinary terms designating difference in composition or structure;

Pechtorf is pitch black to brownish black and is apparently almost homogeneous; the plant remains are so changed as to be practically unrecognizable and the material, when dried, is very similar to Tertiary Pechkohle.

Rasentorf is yellowish brown or wood-brown and the remains of plants are distinct.

Fasertorf designates fibrous remains of plants, penetrating the Pechtorf.

Papiertorf is wood- or soot-brown, with the remains of plants little changed and in separable layers.

Torferde is a peaty earthy substance, friable and with few recognizable plant remains.

Baggertorf is a black-brown, pulp-like peat, obtained by dredging; it dries to a hard mass showing no vegetable structure.

Vitrioltorf contains much ferrous sulphate.

Some of these terms are unimportant, but others are of wide application, designating types which have been considered in all discussions. Von Gümbel[24] introduced a number of new terms, several of which have come into general use. For Pechtorf, he prefers Torfpechkohle, which is the Dopplerit of Haidinger; instead of Baggertorf, he suggests Specktorf and for Papiertorf, Blättertorf. For Fasertorf he would substitute Torffaserkohle; the former term is employed by several writers as descriptive of the felted mass of peat so that it is not definitive. The Conferventorf of Zirkel is

[24] C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitz. d. k. Bayer. Akad. d. Wiss.*, 1883, pp. 128–134.

clearly the Dy-gyttja of H. von Post, the Lebertorf of Caspary, the Sapropel-mud of Potonié.

The salient characteristics of peat deposits are practically the same in all lands and the descriptive terms employed in different languages are almost equivalents; the German Hochmoor may be regarded as the Heathermoor of Scotland, the tourbière haute of Holland and France; the Niedermoor, Rasenmoor, Wiesenmoor and Grünlandmoor are but phases of the bogmeadows, morasses and tourbières basses of other lands; and the Waldmoor is a forested bog. Danish students long ago recognized the types under the names of Lyngmose, Svampmose or Hoermose, for the Hochmoor; Kjaermose or Engmose for the bogmeadows; and Skovmose for the wooded bog. Later German writers in some instances use Hochmoor, Flachmoor and Zwischenmoor. These several types, where the succession is normal, occur in definite relation to each other, marking successive stages in the growth of a deposit.

Growth of Peat Deposits.—The succession of stages in growth of a peat bog was determined in detail more than 100 years ago. All who have visited ponds in process of filling by peat are familiar with the ofttimes concentric bands of differing plant associations around the central water-area. This striking feature was emphasized by observers at a very early date, but a comparatively recent reassertion of the relation, as bearing on the formation of coal beds, seems to have come as a revelation to some, who had already discussed various questions relating to coal and coal beds. It is at least strange that the literature respecting peat appears to be unknown to so many geologists, since it is not confined to brief notes or to memoirs scattered through publications of learned societies, but includes elaborate treatises, some of them more than 100 years old. Many of these appear to be inaccessible in this country, but they have been cited so frequently by writers in Europe that one must believe them readily accessible there. Their existence has been ignored in discussion of coal relations, except where a casual reference enables a writer to show that the credit for an independent discovery does not belong to some later investigator. The facts

concerning growth of peat in water-basins have been known long time and the reports of observations were published widely.

In 1839, Palliardi[25] of Franzensbrunn, Bohemia, described a peat bog near that city, which had been dug for fuel during many years. It covers a space of one by three miles and is from 4 to 5 feet thick, occasionally reaching a maximum of 14 feet. The peat grows again in spaces whence it has been removed. In the second year, algæ appear and in the third there is a more definite vegetation, duck-weed being prominent. During the fourth and fifth years, rushes, sedges and reeds form a floating cover, which the natives term the "cow paunch." Within ten to twelve years the surface is covered with *Erica, Vaccinum, Salix* and *Pinus;* and after thirty to forty years the peat may be cut again, if the water-supply have been constant and the cattle kept off. The deeper the deposit, the denser, more like brown coal and richer in bitumen the peat becomes.

In 1854, Vogt[26] recognized that the first stage is apt to be marked by accumulation of aquatic animals and plants, the latter mostly free algæ. Somewhat later, Heer[27] described the process in detail. In water, organic life begins with the algæ; even pure water, exposed to light and air, is full of little plants with boundless capacity for increase; they quickly appear in vast multitudes, which eventually sink to the bottom and, mingled with newer, higher forms, give a layer of organic matter. Then follow the floating mosses in great lawns with myriads of seeds, which, in spite of their minuteness, in time form a considerable mass of organic substance. Thus the way is prepared for life conditions of flowering plants, which arrive quickly. Bladderworts appear and the water-milfoils root in the soil; water-lilies spread out their leaves and cover the water; reeds press out from the shore; rushes and sedges form a thick complex of roots, which gradually extends over the whole and the water is concealed. This peat mass, constantly growing denser, draws moisture from below and in its soft, damp polster nest *Menyanthus, Andromeda* and

[25] Palliardi, in W. A. Lampadius, "Ueber den Schwartztorf und dessen chemische Eigenschaften," *Journ. f. pr. Chem.*, 1839, 2te Bd., pp. 16–18.

[26] C. Vogt, "Lehrbuch der Geologie," 2te Aufl., 1854, Bd. II., pp. 107, 108.

[27] O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858, pp. 2–5.

heaths, which develop the peat foundation. The lake closed, forest vegetation, birch and fir, advances; the firs do not grow high, but they break off after attaining a certain height and weight, sinking into the soft material, where they are converted into peat, as is the less imposing vegetation. They are readily overturned by the wind, so that peat is crowded with birch and firs. Peat originates partly from mosses, partly from water-plants, partly from swamp-plants, especially the grasses and rushes, partly from woody plants. The hard parts change slowly while the softer parts become a pulpy mass enveloping the others. By climatic changes a Waldmoor may be converted into a Torfmoor and that again into a Waldmoor, giving a section in which a succession of forests is shown.

Three years later, von Post[28] grouped the successive deposits into mud (Gyttja), mud-peat (dytorf) and peat (torf), his conclusions being the outcome of more than 20 years' experience in the peat industry. In 1893, he presented a resumé of his studies as a lecture before the Upsala Institute. He had found that most of the Swedish peat mosses began in water-basins and that the bottom material, clay, mud or calcareous tufa, is sediment from more or less muddy water. A most important stratum is the brown earth, Dy in Swedish, which was formed by precipitation from the brown waters, containing huminic substances, quite analogous to the brown waters of rivers. These huminic substances, leached from accumulations on the land surface, are carried into the lakes by heavy rains. Spring water usually contains salts of calcium, iron and aluminum. When this enters the lake, huminic salts of slight solubility are precipitated, giving the brown layers, the Dy or Dy-jord. As this material goes down, it carries with it algæ (diatoms, etc.), fragments of mollusks, water insects and other débris, including excrement of animals. The passage to ordinary peat is gradual. Dy may be forming in the open portion of a lake while successive stages of bog-development are shown on the shores—and it may re-appear within the peat. Overflow, giving a constant rise of the water-level, may cause destruc-

[28] H. von Post, in *K. Vet. Akad. Handl.* (4), 1861, not seen by the writer; "The Formation of Peat-mosses with Especial Reference to the Theories of A. Blytt," *Bull. Geol. Inst. Univ. Upsala*, Vol. I., 1894, pp. 284–288.

tion of trees on a forested moor and bring about return of the peat moss condition.

Pokorny,[29] after exhaustive study of the Hungarian moors, presented a classification of the deposits and described the stages of growth. He recognized two general types, Hochmoors and Flachmoors, equivalent to the supra-aquatic and infra-aquatic of Lesquereux. The former include both forested and *Sphagnum* moors and are confined to higher land, while the Flachmoors, of many sorts and with many names, are on lower land and have an approximately level surface, contrasting with the convex surface of Hochmoors. The successive stages in growth of the Flachmoor are Hydrophyton, Rohrwald, Rohrwiese, Wiesen, Moorwiese, which correspond to those indicated by observers already cited. It is not necessary to make citations from the works by Rennie, Steenstrup, Senft or others of the earlier investigators in northern Europe, for their conclusions differ in wholly unimportant details from those of the later students. It is certain that the successive stages in development of a peat deposit were recognized more than three fourths of a century ago; since that time, the scheme has been modified only in detail.

In 1910, Potonié, using the Memel delta moor as the illustration, summarized the stages thus, in descending order:

Hochmoor,	Sea-climate Hochmoor, Hochmoor Vorzone, in part with *Arundo phragmites*,
Zwischenmoor,	Conifer inner forest zone, Birch zone,
Flachmoor,	Alder moors, Reeds and rushes, shore zone,
Sapropel deposits.	

In a Hochmoor under a land climate, where the rainfall is less, the succession is completed by a heath stage, during which plants of the heath family take possession of the surface. This, Potonié suggests, may be regarded as the expiring stage of peat growth. If a boring were made through the Hochmoor and underlying materials

[29] A. Pokorny, "Untersuchungen über die Torfmoores Ungarns," *Sitz. Akad. Wiss. Wien*, Bd. XLIII., Abt. I., 1861, pp. 59–65, 86.

to the mineral floor, it would pass through beds of the several stages, each of which would be crossed in following the surface from the Hochmoor to the water's edge.

But one must always bear in mind that the order as given is not absolute; it is merely that observed where the filling of a basin has been continuous and undisturbed; any one or most of the stages may be omitted and any stage may be repeated. Local conditions control the succession. That in Michigan, as ascertained by Davis, is, ascending, (1) A deposit formed by *Chara* and floating algæ; (2) in the shallower water, *Potamogeton* followed by water-lilies; (3) next behind is the floating mat of sedges extending to a considerable distance from the shore; material from the under side of this mat accumulates near the shore and (4) shrubs and *Sphagnum* appear; (5) tamarack and spruce advance with ferns.

These stages are distinct around the open water and the trees are all rooted in the peat, which continues to accumulate while the trees are growing. *Sphagnum* is seen first after the surface rises to 2 inches above the water-level.

This general succession is that observed in peat deposits formed within gradually shallowing water-basins; it applies only locally to the great deposits formed on extensive plains.

The Lebertorf or Sapropel Stage.—Klaproth[30] appears to be the first describer of the material known in later time as Lebertorf. In 1807, he reported the chemical composition of a new combustible "fossil," which came from near Bartenstein in East Prussia. The detailed description of the substance leaves no room for doubt as to its relations. No later notice has been seen by the writer prior to those by Steenstrup and von Post.[31] The former recognized a deposit of amorphous material which rests on the underclay of bogs, while the latter described the Dytorf, which usually underlies the peat. The substance was rediscovered by Caspary[32] in 1870. He

[30] M. H. Klaproth, "Beiträge zur chemischen Kenntniss der Mineralkörper," Vol. IV., 1807, pp. 378, 379.

[31] Streenstrup, summarized by Morlot, trans. in *Ann. Rep. Smithson. Inst.*, 1861, pp. 304 ff.; H. von Post in Swedish Academy, 1861.

[32] R. Caspary, "Lebertorf von Purpesseln," *Schrift. k. phys.-ökon. Ges Königsberg*, 11ter. Jahrg. 1870, Sitz., pp. 22, 23.

had received from Purpesseln near Gumbinnen in East Prussia a peat, so peculiar that he visited the locality to learn its mode of occurrence. The moor was of moderate size and shaped like the figure 8, the broad portions being joined by a narrow strip. In the northern division, under a cover of one foot, he found Wiesentorf, 9 feet thick, black-brown and excellent fuel, containing many hard roots and fragments of stems. This overlies 5 feet of "Lebertorf," which is almost homogeneous, green-brown, very elastic, with coarse conchoidal fracture, with no trace of leaf structure and in appearance almost like animal liver. Occasionally, a root fragment occurs. The substance can be ground to powder under water.

When dried, Lebertorf is wholly different. It is grayish-black and almost invariably laminated, but the laminæ are irregular, with no great extent, often as thin as paper and at times in meshes. It parts very slowly with its water; dried by exposure to the air, it is hard and, when cut with a knife, has brilliant black surface like jet. Under the microscope, fresh Lebertorf is found to consist of minute, light, grayish-brown granules with no trace of structure; bits of crustacean tests and well-preserved pollen of *Pinus sylvestris* are abundant; with them are occasional disintegrated parts of plants, showing cell structure. The southern portion of the moor seems to have only an insignificant trace of Lebertorf, the ordinary peat resting directly on the impermeable blue marly clay.

In 1883, von Gümbel[33] examined Lebertorf from Purpesseln and discovered that it has a felted structure. It contains some insect remains, leaves of grasses and mosses, many round balls, probably spores, and vast quantities of pollen grains, more than 1,000 to the cubic millimeter. Specimens from Kimmersdorf, near Gesterode, and from Doliewen, about 100 miles east from Königsberg, agree in that the cross section shows a uniformly dense mass composed of dull material like Boghead. The laminæ are exceedingly thin and contain clear yellow particles and lens-like segregations of red-brown tint along with several thousand pollen grains to the cubic centimeter. He was impressed by the extraordinary resemblance to cannel and conceived that both substances originated in the same way.

[33] C. W. v. Gumbel, "Beiträge," etc., pp. 132, 133.

Früh[84] remarks that algæ are rare and merely accessory constituents of peat, but in some cases they are essential constituents. Material sent to him by F. E. Geinitz from the bottom layer of a moor at Gustrow was, when dry, hard, brown, homogeneous, with a greasy luster on the cut surface. It is laminated, consists in great part of well-preserved Chroococcaceæ with colonies of other forms of algæ, accompanied by pollen of conifers and *Corylus* as well as by chitinous fragments. He examined Lebertorf from Jakabau, received from Caspary, in which he found pollen and indeterminate remains of higher plants, embedded in a mass composed chiefly of algæ—Chroococcaceæ, Hydrodictyæ and diatoms. Lebertorf from Doliewen, received from Jentzsch of Königsberg, resembles the peat-shale or Torfschiefer from Gustrow and contains, along with pollen of *Corylus* and conifers, well-recognized colonies of *Macrocystis* as chief constituents. The Purpesseln material is similar in composition. Typical Lebertorf has been found at several places in Switzerland, where as elsewhere it consists chiefly of algæ, belonging to genera which are gelatinous. Diatomtorf belongs in this group; he had a specimen from Oldenburg containing 90 per cent. of diatoms.

Jentzsch[85] states that the Lebertorf of Caspary occurs at many places in Germany. Caspary recognized that it has a granular structure; v. Gümbel regarded the granules as exceedingly disintegrated plant remains, while Früh believed them to be algæ. Früh had examined a dried specimen from Doliewen. Jentzsch procured fresh material from that locality and sent it to him. Jentzsch and Caspary could find no evidence that Chroococcaceæ are present in this substance, structureless granules alone were recognized. All Lebertorfs show as chief constituents these roundish granules, which Caspary, v. Gümbel and Jentzsch regard merely as disintegrated plant material; associated with these are pollen from *Pinus* and catkins, bits of plant tissue, remains of crustaceans and often, but not always, diatoms and *Pediastrum*.

In a note appended to this paper, he gives the substance of a letter received from Früh respecting study of the fresh material

[84] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 20–24.

[85] A. Jentzsch, "Mikrostruktur des Torfs," *Schrift. k. ph.-ökon. Ges. Königsberg,* Jahrg. 24, 1883, pp. 47–53.

from Doliewen. This had convinced Früh that the micrococcus-forms are not all Chroococcaceæ. He is certain, at all events, that Lebertorf is not genetically an algæ peat; the algæ are only accessory; pollen plays the chief rôle.

The elaborate microscopical examination of oil shales by Bertrand and Renault after 1890 led them to look upon those shales as accumulations of algæ and remains of other types carried down during precipitation of organic salts—an explanation very similar to that suggested by H. v. Post. These studies recalled similar studies of coal by Reinsch and led to farther study of Lebertorf. Potonié[36] made examinations in many localities, which he discussed at various times, publishing his final conclusions in 1910. The Lebertorf of Caspary, Faulschamm and plankton deposit of authors, is termed sapropellite by him. It contains diatoms, *Pediastrum* and other forms of algæ with pollen of *Pinus, Corylus, Alnus* and *Betula* along with remains of various aquatic animals. It accumulates rapidly in enclosed basins and it has rendered some German lakes so shallow that they are no longer navigable. Jeffrey[37] has observed that the bottom of lakes and ponds becomes covered with vegetable matter swept in by breezes or washed in by rains. This is finer in the deeper, less disturbed portions, but coarser in the shallower parts. In one of his figures, showing the finer type, one finds excrement of fish, snails or amphibia, mingled with pollen of conifers. In the other, showing the coarser material, there are merely remains of roots, leaves and other vegetable "flotsam and jetsam." It is noteworthy that he has found no trace of algæ in the lacustrine muck examined by him. Pollen grains and spores are the most important constituents.

The composition of Lebertorf is variable, certain constituents being more abundant at some localities than at others; but of all the constituents, pollen appears to be the most important; other remains are to be regarded almost as accessory, though always present.

Lebertorf cannot be recognized at all localities. Not infrequently it is absent in the lake deposits of north Germany as also in many of those in Sweden and Switzerland. Undoubtedly, the plankton

[36] H. Potonié, "Enstehung," etc., pp. 19–22.

[37] E. C. Jeffrey, "On the Composition and Qualities of Coal," *Econ. Geol.*, Vol. IX., 1914, p. 733, Figs. 151, 152.

conditions existed, but other growth seems to have been far in excess. Sapropelic deposits, as foundation for ordinary peat, appear to be practically wanting in the United States, as no reference is found in publications by Shaler and Harper, while Davis[38] observed them in only three of the many bogs examined by him in Michigan. The most noteworthy of these is that of the Algal lake; but the forms in that deposit are no longer thought to be algæ, their relations being still undetermined.

Lebertorf conditions may reappear at almost any time during the history of a peat bog. Sernander[39] long ago observed the lens-like structure characterizing portions of moors in Sweden, and Weber had called attention to the same feature in northern Germany. The study of peat deposits in Narke by the Geological Commission led to discovery of the causes and the results were published in 1905. The prevailing opinion had been that shoots of the sphagnum-carpet grow uninterruptedly upward, while the under parts die and are converted into peat. But the sphagnum-tips are killed very easily. On portions of the carpet, where such destruction has taken place, growth ceases, while the surrounding moss continues to grow, so that a depression results. Such depressions are very numerous and are due to various causes. One type, frequently observed in Heath- and Waldmoors, is caused by accumulation of offal from the plants; another is caused by surface growth of liverworts or certain forms of algæ; while a third comes from fires, footsteps or other accidents. As the surrounding *Sphagnum* continues to grow, the depressed spots become filled with water; plants growing on the surface are killed and a Dy-like deposit covers the bottom. The ordinary process of filling follows, sphagnum invades the pool and eventually fills it. The depressions sometimes increase by transgression and attain considerable size. An illustrative section, given by Sernander on his Plate 3, shows that interruptions of this kind are of frequent occurrence. Similar depressions are familiar in bogs of all sorts.

In many cases, especially where the water is calcareous, this

[38] C. A. Davis, "Peat," pp. 203, 247, 267.

[39] R. Sernander, "Guide to Excursions," *Cong. Geol. Int.*, XI., Excursion A7, p. 25.

plankton deposit of bacteria, algæ and especially pollen and spores is concealed in the accumulation of marl from *Chara* and mollusks. At best, it is characteristic only of filled water-basins; it occurs rarely in the great deposits originating on broad coastal or river plains. This is not to assert the total absence of such material. Those great deposits frequently were due to union of numerous smaller ones, each of which filled a depression of moderate extent and afterward expanded by transgression on the plain. Lebertorf may form the floor in the original depressions, though it may be thin, owing to rapid invasion by the plants giving normal peat. In the other condition, where swamps were caused by obstructed drainage, Lebertorf-forming agencies no doubt existed, but they did not predominate. Indeed, those agencies are always present, except during periods of interrupted growth, due to dryness, as one may learn by descriptions of almost all bogs, which show that freshwater algæ along with pollen and spores are accessory constituents at all horizons. Whenever a pond is formed in any considerable deposit, such as Dismal Swamp, originally covering not less than 1,500 square miles, the conditions are prepared for formation of a Lebertorf lens.

The Succeeding Stages Vary.—The earlier studies were made almost wholly upon peat deposits filling former water-basins, which had escaped covering and which had had a, so to say, continuous history from a very early period. When the process of filling was uninterrupted save by variations in temperature or moisture, the normal succession may be shown by the bogs in a great area, as in most of Sweden, north Germany and the British Isles. But where the origin was different, a wholly dissimilar section may be found. Geikie, in describing the moors of Scotland, says that they often mark the sites of lakes and ponds, but at times they cover the ruins of ancient forests. When the forest was overthrown, drainage was intercepted, stagnant swamps were formed and water-mosses took root. He refers to several illustrative instances. In the Forest of Mar, large trunks of Scotch fir, which fell from age and decay, were soon immured in peat, formed partly from decay of their perishing leaves and branches and partly from the growth of *Sphagnum* and

other marsh plants. On Loch Brown, the peat cover was completed over the site of a decayed forest in less than 50 years. In 1756, the Wood of Drumlanrig was blown down and experienced a similar fate.[40]

Miller[41] has cited the Earl of Cromarty's description of peat growth in central Ross-shire. When very young, the earl had observed a wood of very ancient trees, doddered and mossgrown, evidently passing through the last stages of decay. Many years later, he passed through the same district and found that the wood had disappeared, while the heathy hollow was occupied by a green stagnant morass. In his old age, he revisited the locality; the surface was irregular and pitted, for the highlanders were digging peat in a stratum several feet deep. The aged forest had been replaced with an extensive peat moss.

The sphagnum-stage is not rarely the first. Dachnowski[42] found *Sphagnum* growing in Ohio on wet sand, where it formed tussocks often more than 4 feet high. This matter will be considered in another connection.

It may be well to note, parenthetically, some other observations by Dachnowski. Davis had recognized in Michigan that *Sphagnum* is indifferent to calcareous salts, growing as well where the water is hard as where it is soft. In Ohio, the nature and quantity of the mineral salts seem to be unimportant, since the heath-sphagnum meadows are abundant in counties where they rest on limestone, while in one locality *Sphagnum* grows in profusion near springs charged with calcium carbonate; this plant in Ohio as in Michigan is indifferent to that salt, for Dachnowski found it abundant in one locality and wanting at another, the conditions being the same in both. Deficiency in mineral matter does not prevent growth of trees on peat; they grow well on the floating mat of heath-sphagnum and in places where the peat is 30 feet thick. In Ohio, the heath-association does not mark the final stage, for it is followed by the bog shrubs. The final stage is marked by the bog-forest association,

[40] A. Geikie, "The Scenery of Scotland," 2d ed., London, 1887, pp. 388–392.

[41] H. Miller, "The Old Red Sandstone," Boston, 1860, p. 174.

[42] A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 224–256.

of which tamarack (*Larix laricina*) and arbor vitæ (*Thuja occidentalis*) are among the first to invade the surface. When bog conditions have disappeared and the surface has become covered with mould, deciduous trees advance and crowd out the conifers. As the mould-cover is very thin and the wet peat is reached very quickly, the roots of this forest group rarely extend downward more than a foot, but they spread out in all directions, as do those of the conifers, thus giving stability.

Structure and Constituents of Peat Deposits.—An intimate examination of a peat deposit leads to conviction that the process of accumulation may not be so simple as is indicated in the preceding generalized paragraphs. There are many modifying conditions.

A peat bog shows, speaking generally, a thin layer of living plants on top, under which the vegetable matter becomes more and more disintegrated downward until, toward the bottom, the greatest part shows no vegetable structure to the unaided eye and the mass consists of felted stuff cemented by a humus-like substance. This cement is removable easily by weak solution of caustic potash and the dried residue tends to fall to a powder. The change downward is not, however, always in increasing ratio.

A peat deposit is rarely continuous from bottom to top, but is commonly divided at irregular distances by partings of one sort or another. These may be thin, consisting of finely divided mineral matter holding a charcoal-like substance, Torffaserkohle of v. Gümbel, or they may be thicker and composed of sand, clay or other transported matter. The thickness of individual partings varies greatly, so that the intervals between the several benches of the deposit may increase or decrease. Lorié's[48] observations in Holland, Belgium and north France make this variation sufficiently evident. The benches themselves differ in peculiarities of the peat and in character of the ash, as one would suppose in view of the different plant-associations marking the several stages of growth.

The opinion has been expressed that a layer of organic material is essential as prerequisite to formation of a peat deposit, and the assertion has been made that, in any event, a Hochmoor with its

[48] J. Lorié, "Les dunes intérieures," etc., *Arch. Mus. Teyler*, II., Vol. III., pp. 424–427, 444.

mosses cannot begin on inorganic material. This material can hardly be determined satisfactorily either positively or negatively, as the thickness of the organic layer is regarded as immaterial, one author holding that it may be so thin as to be unrecognizable, while he still insists that it must be present. There can be no doubt that, when a Hochmoor increases by transgression, it is likely to rest in part upon inorganic material. Rohhumus on bare rock, the sphagnum-peat described by Dachnowski and some instances to be noticed on a later page appear to indicate that a moss peat may begin on inorganic surfaces. At the same time, it is beyond all question that, of deposits originating on the surface of plains, a very considerable proportion began on forested areas, where the litter afforded excellent base for peat growth after the drainage had been impeded. Shaler, many years ago, referred to transgressing bogs in New England, which invaded forests and eventually killed even the water-loving trees. Lewis[44] says that in the lowland mosses of Wigtonshire, Scotland, the till surrounding the original area of obstructed drainage carried birch and *Calluna,* which were replaced gradually by hazel and alder. In these deposits, *Betula* is abundant even on the floor. Sanford regards the Everglades of Florida as due chiefly to impeded drainage. Peat operators have long known that if the bog be stripped clean to the underclay, peat growth begins very much more slowly than when a thin cover of vegetable matter has been left on the clay.

The partings in peat deposits, when consisting of clay, sand or marl, indicate subsidence or flooding. They may be so numerous as to render the mass worthless, the laminations of peat and foreign matter being alike thin; or there may be alternations of fairly clean peat with layers of intimately mingled organic and inorganic materials. The former indicate very frequent floodings, while the latter tell of a long period of subsidence interrupted by longer or shorter periods of comparative stability. A good illustration of the latter condition is that given by Debray[45] in his description of a

[44] F. J. Lewis, "The Plant Remains in the Scottish Peat Mosses," Pt. I., *Trans. Roy. Soc. Edinb.,* Vol. XLI., 1906, pp. 699–722.

[45] L. Debray, "Étude géologique et archéologique de quelques tourbières

section in the valley of the Somme. The deposit is 8 feet thick in 13 wholly distinct benches, varying in thickness from one third to one meter. Four benches, aggregating 2 meters, are of excellent peat, but the others are, in several cases, little better than carbonaceous shale; the ash is calcareous. Similar illustrations are to be found in the American treatises.

In areas where floodings of muddy water are wanting and where climatal variations show little change from year to year, there may be no benches and the mass may be continuous from bottom to top. Johnson[46] has described a peat deposit, which shows about 15 feet of sphagnum-peat, practically continuous. Cook,[47] in discussing the bogs of New Jersey, states that the peat is so crowded with logs of *Chamæcyparis* that one has difficulty in thrusting a sounding rod to the bottom. The condition is the same throughout, even where the peat is 13 feet thick; the Waldmoor growth was uninterrupted. A similar story is told by the cypress swamps. R. M. Harper and others have shown that, in the cypress swamps of Florida, the peat is so filled with logs and woody roots as to be without commercial value. Lyell's[48] statements respecting the cypress swamps of the Mississippi region are in similar terms; for he says that the contractor, in excavating for foundations of the New Orleans gas works, soon discovered that he had to deal not with silt but with buried timber; the diggers were replaced with expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that, in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for three tiers of stumps in the nine feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them." It should be said that the whole

du litoral Flamand et du Département de la Somme," *Mem. Soc. Sci. Lille*, Vol. XI., 1872, pp. 471, 472, 475–478.

[46] D. W. Johnson, "The Shoreline of Cascumpeque Harbor, Prince Edward Island," *Geogr. Journ.*, 1913, pp. 152–164.

[47] G. H. Cook, "Geology of New Jersey," 1868, pp. 301, 355, 360, 484.

[48] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., pp. 136, 137.

delta region of the Mississippi is subject to frequent floodings, but, in a great part of the area, the dense "cane brakes" act as filters, so that the water is freed from its load of silt and continuity of swamp growth is uninterrupted.

There are serious interruptions in the growth, which are not due to flooding or to merely local variations in the water-level but rather to widespread changes in conditions. Benches in thick deposits frequently appear to represent cycles of deposition and these often are separated by thin partings of exceedingly fine mineral matter, containing more or less of fibrous material resembling the mineral charcoal of ordinary coal. Such partings were explained long ago by Lesquereux as due to a period of dryness, when the peat ceased to grow and the surface was destroyed by oxidation to a greater or less extent. The period of exposure may be brief or it may be long continued. A. Geikie and Lewis have made clear that peat forms now in only exceptional localities within Scotland, as the climate has become less moist; and Skertchly asserts that peat is no longer forming in the Fenland of England, save in a dark narrow valley of Suffolk. The peat is wasting in those areas. Similar statements come from other parts of northern Europe. Leaving out of consideration *Taxodium, Nyssa,* certain palms and the trees of the Kampar areas, it is certain that most of the trees growing on peat do not thrive when the material is very wet. Some, it is true, show a notable degree of adaptation. C. A. Davis saw in Michigan a birch in healthy condition, though its roots had been covered with water during more than a year; and there are other types which do well if only the water cover be absent during a considerable part of growing season: the tamarack at times takes root far out on the floating bog, but it grows slowly as do other trees which accompany it. One may learn much respecting changing conditions during the growth of a peat deposit by noting the distribution of trees.

Zincken[49] cites Hartig as saying that in the "rothe Bruche" on the Harz there occur in the lowest 5 feet of the 39 to 40 feet thick Hochmoor, firs with stems 18 inches thick. Higher, is a layer with large pines, on which is another with smaller plants of the same

[49] C. Zincken, "Die Physiographie der Braunkohle," Hannover, 1867, p. 38.

genus, while in the next layer the forms are stunted. Both firs and pines are wanting in the upper portion of the mass. Sernander and Kjellmark[50] discovered that in northern Nericke, Sweden, the succession is (1) Living peat; (2) sphagnum-peat; (3) bed of stumps and roots; (4) sphagnum-peat, passing downward into peat composed chiefly of *Phragmites* and *Equisetum*. The stump layer has birches with needles and bark of *Picea abies, Pinus sylvestris* with fruits, seeds and leaves of other plants.

In the Harz locality, increasing wetness destroyed the trees; in Nericke, trees advanced when the moisture decreased, only to be destroyed when once more the moisture increased.

According to Poole,[51] the great turbary, known as the South Marsh, is double. The upper part is 7 to 8 feet thick and is worked for use as fuel; the lower portion, of about the same thickness, has on its surface everywhere the stumps and roots of trees, standing as they grew. Woodward states that the peat is composed mostly of sedges, so that it is clear that the restoration of marsh conditions led to destruction of the forest which had grown on the bog surface. Skertchly[52] recognized five successive forests in the peat of Wood fen near Ely. Number 1, at the bottom, is of oak and the trees are rooted in the Kimmeridge Clay; Number 2 is at an average distance of 2 feet above the other and consists of yews and oaks, the lower forest having perished before this began, as roots of Number 2 sometimes rest on stumps of Number 1; at 3 feet higher, are the remains of another forest, all firs, and another is just above that; while immediately below the present surface is still another, resembling the modern trees of the region. There were five successive forests, of which all except the first were rooted in the peat. As Skertchly remarks, it is evident that, while in general the climate of the Fenland may have favored peat making, still there were intervals when peat was formed, if at all, in very limited areas, the other portions being

[50] R. Sernander und K. Kjellmark, "Eine Torfmooruntersuchung aus dem nordlichen Nericke," *Bull. Geol. Inst. Upsala*, Vol. II., 1896, pp. 321, 324.

[51] G. S. Poole, cited by H. B. Woodward, in "Geology of Eastern Somerset," Mem. Geol. Surv. London, 1876, pp. 146, 156.

[52] S. B. J. Skertchly, "The Geology of the Fenland," pp. 130, 151, 165, 168, 169.

invaded by forest. The non-peat-making intervals must have lasted more than 150 years, as appears from the size of the trees. The region is now passing through another dry period and the peat bogs are not increasing. De la Beche[53] has referred to the Drumkelin bog in Donegal, Ireland, as affording a striking illustration of interruption in accumulation of peat. At 16 feet below the surface and resting on 15 feet of peat, a house was reached 12 feet square, 9 feet high and constructed wholly of oak. When the peat had been removed from about the house, a paved pathway was disclosed, leading to a hearthstone covered with ashes. Near the house were stumps of oak trees, which evidently were growing when the house was inhabited. A layer of sand had been spread over the surface before the little building was erected. This pause in growth of the deposit was of sufficiently long duration to permit forest growth and to invite habitation. It was followed by return of swamp conditions, during which 16 feet of peat accumulated.

Geikie[54] has recorded several cases of which only two need be recalled here. At Strathcluony, three tiers of Scotch firs were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss, one of standing firs with branching roots at 6 feet below the surface, a second at 12 and a third at 16 feet below the surface; so that, counting the present surface growth, four forests have grown there since the bog-making began; that is to say, the swamp conditions have been interrupted four times by periods of lessened moisture, the last being the present. The preceding three were succeeded by periods of wetness during which peat-making proceeded vigorously. It must not be supposed that even in the drier periods accumulation of peat ceased wholly. It has been known a long time that the offal of conifers can accumulate as peat. Reinsch[55] says that in the Fichtelgebirge needles of Fichten, Tannen and Föhren are important as peat-making material and that in time they accumulate in such quantity that a quaking bog is the result. One must insist here that the mere accumulation of peaty materials around and

[53] H. T. de la Beche, "The Geological Observer," Amer. ed., 1851, p. 134.

[54] J. Geikie, "The Great Ice Age," 3d ed., London, 1895, pp. 286–293, 303.

[55] H. Reinsch, "Ueber den Torf des Fichtelgebirges," *Journ. f. pr. Chem.*, Bd. XVI., 1839, p. 486.

between the trees was not the direct cause of their destruction; but accumulation in an increasingly moist climate might well contribute indirectly by retention of moisture and thereby bringing about the condition in which proper aeration of the roots could not take place.

Lesquereux, Heer, Geikie, Grand'Eury and others have shown by sections in Britain and central Europe this alternation of swamp and forest conditions, while Steenstrup, Blytt, von Post, Andersson, Sernander and others have made the matter abundantly clear for the Scandinavian areas.[56]

The causes of these alterations have been subject of much discussion, as they are among the most striking features of peat deposits. Andersson[57] maintains that the presence of tree stumps in a bog is not necessarily evidence of actual change in climate; that can be explained by the ability of peat bogs to invade forests and to convert them into swamps, as has been proved by several Swedish observers. But this familiar fact can explain only the presence of trees rooted in the underclay; it does not explain the presence of a forest layer with its roots wholly enclosed in the peat. This indicates invasion of the swamp area by the forest. A change in direction or extent of drainage might answer well as explanation of local appearance of trees, for only a slight lowering of the water-level would suffice. But changes in drainage or the encroachment by swamps, while accounting well for local variations in a swamp, great or small, cannot suffice as explanation of widespread variation appearing almost contemporaneously in immense areas. Some general cause must be sought. Blytt and von Post have presented incontrovertible evidence of alternations in climatal conditions throughout Scandinavia; Lewis has done the same for Scotland as J. Geikie has done for a wide area; while Schreiber,[58] after detailed study within the province of Salzburg, showed that the variations in bog life were associated with climatal changes involving migration of the snow-line in the Alpine regions.

[56] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 604–613.

[57] G. Andersson, "Studier öfver Finlands torfmosser och fossila kvartarflora," Bull. Com. Geol. de Finlande, No. 8, 1898, p. 186.

[58] H. Schreiber, "Vergletscherung und Moorbildung in Salzburg." Separate from *Oester.-Moorzeitschr.*, Staab, 1912, pp. 14, 15.

Preservation of Vegetable Matter in Bogs.—The chemical processes leading to conversion of plant matter into peat do not fall within the scope of the present inquiry, but some features must be considered, though without reference to their causes.

Even a casual examination is enough to convince the observer that these processes do not attack all plants or all portions of a plant equally. Bunbury[59] says that the peat in a great bog was found to be merely a black mud, so decomposed as to show no vegetable structure; but at 15 feet down in this mud there was found a horizontal layer, 2 to 6 inches thick, of compressed, undecayed moss, *Hypnum fluitans,* without admixture of other material. The peat below this layer is like that above it. Skertchly[60] notes a similar case. In the turbary near Ely, the peat is digged to a depth of 4 feet. At the top for about a foot it is chestnut brown and not bedded; this is succeeded by 3 feet of black peat, which is bedded, contains roots of reeds, flags, etc., but in the mass shows vegetable structure obscurely; at the bottom is a layer, almost wholly *Hypnum,* which dries to a yellow tint and preserves the vegetable structure. It is well known that the soft parts of plants disappear quickly to become the pulp, in which the harder parts are embedded and of which they themselves eventually become part.

The bark of trees is resistant, even that of trees whose wood decays rapidly. Darwin[61] remarks that in the valleys of Tierra del Fuego, it was scarcely possible to crawl along, the way being barricaded by great mouldering trunks, which had fallen in every direction. When passing over these natural bridges, one's course was often arrested by sinking knee-deep into the rotten wood; at other times, when attempting to lean against a firm tree, one was startled by finding a mass of decayed matter, ready to fall at the slightest touch. There are few living in the temperate zone who have not been startled in like manner by the crashing of a log on which they had set themselves in the woods. The bark had remained sound

[59] C. J. F. Bunbury, "Notice of Some Appearances Observed in Draining a Mere," *Quart. Journ. Geol. Soc.,* Vol. 12, 1856, pp. 355, 356.

[60] S. B. J. Skertchly, "Geology of the Fenland," p. 135.

[61] C. Darwin, "Journal of Researches," Amer. ed., New York, 1846, Vol. I., p. 302; Vol. II., p. 44.

though the wood was wasting away. The rate of decay is indefinite. Darwin estimated that in the neighborhood of Valdivia in Chili, a stump of 18 inches diameter would be changed into a heap of mould within 30 years; but in Java, Koorders, cited by Potonié, saw much fallen timber, decades old yet still in condition for export. In the northern part of the United States, stumps of maples, elms and spruces, 18 inches to 2 feet or more in diameter, are often sound enough after 25 years of exposure to require blasting for their removal. The wood of oaks and conifers is especially resistant, yet even those may go rapidly. Lesquereux,[62] in referring to the sunken forest of Drummond lake in the Dismal Swamp, says that standing stumps of bald cypress (*Taxodium distichum*) are decaying so that many of them are hollow. Fruits and leaves of trees, falling into the water and drifting, are arrested by the hollows of these trees and fill them almost completely. De la Beche,[63] in discussing the decay of plants, observes that "this kind of decay is still more instructive where upright stems of plants in tropical low grounds, liable to floods, retain their outside portions sufficiently long to have their inside hollows partially or wholly filled with leaves and mud or sand, the whole low ground silting up, so that sands, silt and mud accumulate around these stems, entombing them in upright position, without tops, though their roots retain their original extension." Potonié, in 1895, called attention to the fact that hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

Generally speaking, the wood of deciduous trees decays rapidly while that of conifers changes slowly. Lesquereux, on the page preceding that just cited, records that in Denmark, about 20 miles below Copenhagen, there is an extensive grassy plain with one foot of humus as the soil. Underlying that is a bed of peat-like material, 6 feet thick, composed wholly of closely packed, flattened birch bark. This, free from earthy matter, is cut out and dried in long rolls. The woody part of the stems, now nearly fluid or transformed into a very soft yellow mud, is at the bottom of the deposit, whence it is

[62] L. Lesquereux, "Geology of Pennsylvania," 1858, p. 847.

[63] H. T. de la Beche, "Geological Observer," p. 133.

removed in buckets and dried for fuel. Debray[64] found plant remains resembling burnt straw within the peat,—the Torffaserkohle of v. Gümbel, a by no means rare occurrence in peat. Birch bark retains its silvery color; the wood of oak is hard and black, but other woods are soft, yellowish and shrink much in drying. Debray observed in this peat of the Somme valley, some shrubs in an inverted position, which he very properly regards as proof that they did not grow where found. Skertchly[65] reports that the birches of Ruskinton fen are represented only by their papery bark, which retains its silvery luster; the bark of elms is preserved but the wood is rotten like touchwood; wood of oaks, always stained black, is often sound enough to be used for gates and fencing posts, though usually fit only for fuel; but the wood of conifers is little changed, that of yews retains the peculiar brown color, while that of firs is as white and sound as if from living trees and the odor of turpentine is distinct when the wood is cut. The *Chamæcyparis* of the New Jersey peat is so good that much of it can be used in building and in cabinet work; the preservation of oak in bogs of Ireland and Switzerland is familiar to all who have visited those countries.

The wood in peat deposits does not always represent material dead or wasted prior to burial. The logs and stumps in the lower portion may be remains of a forest destroyed by advance of the swamp, but that is not necessarily the case with such remains higher in the peat. Trees growing on the surface of peat are uprooted readily by the wind as they have an unstable soil; if the forest be not too dense, such overturned stems sink into the pulpy mass and the deposit becomes crowded with stems, embedded before decay had set in.

Thus one finds logs, in all stages of decomposition, embedded in pulpy matter, derived largely from the soft parts of plants and holding also the waste of various woods as well as abundant pollen, spores, bacteria, fungi and freshwater algæ.

Effect of Pressure on Peat.—Many years ago Lesquereux asserted that peat has a laminated structure and since his time other observers have referred to laminated peat; but this lamination is not

[64] L. Debray, "Étude Géologique," etc., pp. 445, 449, 450.

[65] "Fenland," pp. 160, 161.

so distinct in ordinary peat as to attract the attention of a casual observer. Under pressure, however, the structure is well-defined.

Spring[66] tested the effect of compression on Holland and Belgian peat, mature but retaining much material showing organic structure. Under pressure of 6,000 atmospheres, this was changed into a black, brilliant block, with all the physical aspect of a coal; the fractured surface, as seen under the glass, was distinctly laminated, while evidence of organic texture had disappeared. Under this pressure, the peat became plastic and ran out into the chinks of the compressor. Thoroughly matured peat, after this compression, does not absorb water and does not return to its original form. von Gümbel[67] subjected spongy sphagnum-peat to a pressure of 6,000 atmospheres, by which it was rendered apparently homogeneous and as hard as pasteboard. A pressure of 20,000 atmospheres increased the density to that of sole leather. In each case, lamination was distinct and the streak was lustrous, but when placed in water, the material swelled to almost the original bulk. Evidently, pressure of brief duration suffices to produce permanent physical change in well-matured peat though not in the immature substance. But one is not dependent on laboratory results; the experiment has been performed in nature many times and on a grand scale.

Forchhammer,[68] in his descriptions of dunes on the Baltic coast, of Denmark, states that among those dunes are numerous lakes and ponds characterized by abundant vegetation and by formation of peat. When an unusual storm passes over the dune, sand is blown into the ponds and puts an end to growth of peat. This buried peat, known as Martörv, is exposed when currents cut away the coast. The phenomenon is not confined to the mainland; on the north side of Seeland, there was a pernicious stretch of quicksand early in the eighteenth century but, before 1760, it had become

[66] W. Spring, "Recherches sur la proprieté que possedent les corps solides de se souder par action de la pression," *Bull. Acad. Roy. Belg.*, II., Vol. 49, 1880, pp. 367, 368.

[67] "Beiträge," etc., pp. 127, 128.

[68] G. Forchhammer, "Geognostische Studien am Meeres-Ufer," *Neues Jahrbuch,* Jahrg. 1841, citations from pp. 13, 14.

watered and covered with a dense forest of fir. On the border of the dune, the sand covered part of a peat-moor, where it had stopped growth while accumulation continued unchecked on the uncovered portion. Peat from the latter does not differ from that of bogs in the neighborhood, but that from the sand-covered portion has been changed into a wholly different substance. Ordinary Moortorf, dried, weighs from 16 to 20 pounds per cubic foot, but that which has been compressed by the dune weighs 78 pounds. In ordinary peat, dried, one finds scarcely any trace of layers, but this compressed peat is almost shale-like in lamination. The Seeland peat is formed mostly of offal from a forest vegetation, but in hand specimens one cannot distinguish it from brown coal.

v. Gümbel in 1883 found that the Martörv has alternating bright and dull laminæ, the bright portions consisting chiefly of ribs and hard parts of grass leaves with admixture of other parts, pollen, etc. He thought that it bears much resemblance to Lebertorf, but it is clearly of different origin. One would surmise from the conditions that this Martörv contains both mature and immature peat. The observations by Jentzsch are confirmatory. He remarks that the Martörv found near Rixhoft in East Prussia is derived without doubt from the Bielawe and other moors, that it is compressed material from underneath the dunes, which now separate those moors. Nilson[69] has described a vast gravel deposit which follows the Baltic coast of Sweden for a long distance beyond Ystad and, at various places, rests on peat.
This material is similar in composition to the recent peat of Sweden.

Lesquereux's[70] description of conditions in the valley of the Locle in Switzerland is equally to the point. On the side of the valley, under a heavy bed of marl, he found 3 inches of compressed material, hard, fragile and with brilliant fracture; lower down the slope, where the marl is but 4 feet thick now, the deposit is 6 to

[69] Nilson, cited by J. Geikie, "Prehistoric Europe," p. 473.

"The peat under this stone wall is so compressed that, when dry, it is almost as hard as brown coal; the trees also are, like the layers of coal, pressed together, and when a fir chip is broken, it is found to be black and shining in the cross-section, all the result of great pressure and age."

[70] L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. Sci. Nat. Neuchatel*, Vol. III., 1845, pp. 95, 127.

7 inches thick and retains some peat-like features, but is a passage from the lignite of the border to the peat of the open valley, which has been growing continuously, so that it is now 8 feet thick. In another connection, he remarks that some deposits of lignite are surrounded by peat. Goeppert's[71] observation is very similar. A deposit of peat was found in the low part of a valley near Helvetihof in Upper Silesia. On both sides of the valley, a portion of the deposit is covered with 2 to 10 feet of soil and sand beds, under which the peat has been changed into a distinctly laminated, hard black mass, almost like stone coal; whereas the peat in the open valley, uncompressed, has the usual brown color and comparatively loose structure.

Preservation of Peat Deposits.—The surface of a dead bog is often irregular as though it were wasting away; the peat-cover of a drained area, under cultivation, disappears within a few years as ploughing exposes more and more of it to oxidation, drying and the winds. A casual observer of the "hag" region of Scotland feels justified in believing that peat is formed only to decay and that little of it will survive to reach a more advanced stage of transformation. This is the conclusion reached by an eminent student of coal problems and his opinion appears to have been accepted as fact by several authors. But the conclusion cannot be accepted as final; it seems to be based on incomplete observation or on lack of familiarity with conditions in great areas. The process of removal, where man does not interfere, is slow, because peat, with its felted structure and its obstinate retention of water, offers great resistance to erosion. A very thin cover of fresh peat protects itself and the underlying rock from removal. The effect of oxidation is not rapid, as it is necessarily superficial, circulation of air in the drying peat being confined to the newer portion.

Lowering of the water-level does not mean that the surface is to become dry and pulverulent, to be swept away by the wind. In most cases, that lowering of the level leads to invasion by plants which cannot endure wet conditions, to the growth of a rather dense cover of vegetation which, by its accumulating offal, protects the

[71] H. B. Goeppert, "Abhandlung eingesandt als Antwort auf die preisfrage," etc., Amsterdam, 1848, pp. 104, 105.

peat already formed and adds to the mass. As soon as local or general conditions again become favorable, peat growth in the ordinary way would be resumed and the invading vegetation would be killed. The record of alternating wet and dry periods is distinct in very many deposits which offer no evidence of serious waste during the passage from one to the other. Some of the less moist periods must have continued for centuries, if one may judge from the age of rooted trees in the forest layers. Certainly the desiccation process did not extend deeply, for the roots of trees in those layers are spread horizontally in shallow depth, as though avoiding the wet peat below, just as do the roots of the invading forest trees now.

It is wholly possible that comparatively little of the peat now forming will reach a later stage in transformation; the agricultural importance of peaty lands is understood, as is also the method for their preservation, so that the work of drainage and reclamation will be more and more extensive in the future. But with that this study is not concerned. The questions involved deal with conditions prior to man's interference with nature's operations. The evidence all encourages the belief that a very great part of the older peat has been protected and that the peat now forming in uninhabited regions will be protected in like manner, to become a genuinely fossil fuel. Buried peat deposits are known throughout the world.

Forchhammer, Jentzsch, F. E. Geinitz and others have described dune-covered bogs along the Baltic shores and C. A. Davis has referred to the same condition in Michigan. The process continues in those regions. One finds frequent notes respecting submerged bogs, often continuous with living bogs on the shore, as though the swamp had advanced up the surface during the subsidence. In some localities, portions of the submerged bog are already covered with materials from the land, while other portions are still free from cover; in such cases, the overlying deposit should contain marine forms. At times, the influx of inorganic matter continues until land conditions, have been restored and the peat extends over the new surface. Borings in northwestern Europe pass through a succession of peat bogs separated by sand or clay. Similar relations are exposed in deep excavations and occasionally in uplifted areas.

J. Geikie[72] has given numerous instances of submerged deposits on the coast of Scotland. Farther inland, in the Carse lands on both sides of that country, deeply buried deposits have been exposed by the rivers. The River Tay has cut its channel down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. In some parts of the wide Carse area, this extensive deposit rests on alluvial sands but in others on marine clays. The peat is much compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, it is marked off sharply from the overlying clay and silt, but, at times, it is covered with vegetable debris which was drifted in from places higher up in the valley. Skertchly[73] found that on the Isle of Ely the peat underlies 4 to 8 feet of silt and clay and rests on clay, both roof and floor being marine, the peat marking an interruption in deposition of the clays. Several peat beds are within 12 feet; the lowest, 18 inches thick, is normal, black and clean; but the higher peats are irregular and impure, mingled with clay, showing the contests between plants and muddy water. Travis[74] has described a case of marine association, which shows also a by no means unusual relation of the beds. The Seaforth Dock excavation, 40 feet deep, 180 wide and 900 long, exposes two beds of peat. The lower, 18 to 24 inches thick, rests on gray sand and is shown for about 280 feet. At 5 to 10 feet higher, the interval being filled with *Strobicularia* clay, is the upper bed, 12 inches thick, which is exposed for 480 feet. It overlaps the lower one, which thins out. The peat in both bands is firm, woody, with occasional fragments of bark and twigs, but it contains no stumps or trunks of trees.

Lorié has recorded a great number of borings in Holland, which illustrate the succession of buried peat beds, separated by sands deposited beneath the sea. Rutot has given records showing peat beds intercalated in marine sediments on the coast of Belgium.

[72] J. Geikie, "The Great Ice Age," 1895, pp. 290–293.

[73] S. B. J. Skertchly, "Fenland," pp. 140–143.

[74] C. B. Travis, "Geological Notes on Recent Dock Excavations at Liverpool and Birkenhead," *Proc. Liv. Geol. Soc.*, Vol. XI., 1913, pp. 237–275.

Sirodot[75] refers to a locality, where one finds a series of alternating peat and marine deposits, which he explains by supposing that a bar was formed and broken repeatedly, so that the enclosed area was alternately freshwater and marine.

But this burial comes also to inland deposits, to those on great deltas or at the heads of long estuaries, where the covering material is of freshwater origin. Much of the Holland-Belgium-France area, in all more than 7,000 square miles, was not under the sea at any time since the peat began to form; the great peat bed of the Ganges delta is at 20 to 50 feet below the somewhat irregular surface and is covered with river silts in an area of not less than 2,500 square miles. Entombment seems to be the fate of large and small alike. Phillips[76] has recorded the section of the Holderness peats, thus: (1) Clay; (2) peat, with plants, trees and roots; (3) variegated clays, with freshwater *Lymnæa;* (4) peat, like No. 2; (5) clay with freshwater Cyclads; (6) bituminous clay; (7) coarse sandy clay. Number 2 is the persistent member of the section, but varies greatly in thickness and character. Near Hull, it is 30 feet below the surface and 2 feet thick, containing large trees, Buried swamps abound on the Atlantic coast of the United States, especially along streams emptying into the long estuaries occupying "drowned valleys." One citation suffices to illustrate the conditions. Berry[77] says that such swamps are exposed by erosion at many places along the James, Rappahannock and Potomac Rivers, all emptying into Chesapeake bay. Most of those observed in 1907–09 were cypress swamps, though some were of the open type with birch, oak, pine and other forms. When quiet conditions accompanied subsidence of the forest bed, clay is the roof, containing *Unio,* if the locality be near the head of the estuary, or *Rangia cuneata,* if farther down within reach of saline water. This condition of quiet subsidence is shown in the photograph of an exposure

[75] Sirodot, "Age du gisement de Mont-Dol," etc., *Comptes Rendus,* Vol. 87, 1878, pp. 267–269.

[76] J. Phillips, "Illustrations of the Geology of Yorkshire," 2d ed., 1835, Vol. I., pp. 25–27.

[77] E. W. Berry, "Pleistocene Swamp Deposits in Virginia," *Amer. Naturalist,* Vol. XLIII., 1909, pp. 432–436.

near Tappahannock, Virginia, where a bed of massive hard peat is exposed for half a mile. This is covered with plastic clay, 1 to 4 feet, underlying 10 to 15 feet of coarse sand. One sees many cypress stumps in place, with their "knees" projecting into the sand. Where the subsidence was accompanied or followed by disturbance, the evidence appears in the more or less planed or eroded surface on which gravel or sands rest, as is shown in a photograph of peat with embedded cypress stumps, which is unconformable by erosion to the overlying sands.

Greater interest attaches to the interglacial buried peats, which have been covered with material transported during the Ice Age. These, underlying clays, sands or gravels, exhibit many features which are important here. Such deposits have been observed in many lands.

The deeply buried peat of Montgomery county, Ohio, originally studied by E. Orton, Sr., has been restudied by Dachnowski.[78] The exposure is in the bank of a tributary to the Miami River and underlies 80 to 100 feet of stratified clay and gravel. There are indications that the deposit is part of a large area and that it marks the deeper portion of an extensive water-basin. The thickness, as now exposed, is from 1 to 4 feet, but, 45 years ago when Orton's description was written, it was from 12 to 20 feet. The uppermost layers contain undecomposed sphagnum-mosses and underlie fine silty blue clay. The lower portions grade into a well-decomposed, very compact peat which holds fragments of wood. This peat rests on several feet of fine sand underlain by clay and gravel. Near the southern margin, according to Orton, a large quantity of timber was found, roots, branches and twigs, much of which had been flattened by pressure. The wood is largely but not exclusively coniferous. Newberry[79] recalled Collett's discovery in much of southern Indiana of a buried deposit, 2 to 20 feet thick, containing rooted stumps. In later years, W J McGee, F. Leverett, F. B. Taylor and J. W. Goldthwait have described interglacial deposits, some of which are very extensive.

[78] A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 102, 103.

[79] J. S. Newberry, "Geological Survey of Ohio," Vol. II., 1874, pp. 30–32.

Dunlop[80] has given details of a section observed by him at about two miles from Airdrie, Scotland. The order, descending, is (1) Alluvium, 3 feet; (2) peat, with trees standing up through it, 2 feet; (3) Upper Boulder clay, containing a 4-inch layer of vivianite near the bottom, 4 feet; (4) sand with partings of fine clay, 11 inches; (5) peat, 1 foot 5 inches; (6) Boulder clay, not measured. The upper peat bed is recent, but the lower is interglacial. The peat of the latter splits readily into layers and darkens somewhat rapidly on exposure. Some layers consist of seeds of *Hippuris vulgaris* and *Menyanthus trifoliata;* others are wholly of mosses and, near the bottom, are some containing abundant remains of beetles. But no traces were found of the trees usually found in bogs, aside from some leaves resembling willow. The cover is sand but silica is practically wanting in the peat, which, air-dried, contains 6 per cent. of ash, mostly oxide of iron. In this bed are boulders of sandstone and gneiss, varying in size and distributed irregularly; all are waterworn and those which are little disintegrated show ice-markings.

Reid's[81] report, on behalf of a committee, which studied the deposits at Hoxne, on the border of Norfolk and Suffolk, England, relates that at that place a bed of lignite, 1 to 3 feet thick and disappearing at the borders of the valley, rests on a carbonaceous clay containing lacustrian shells and some drifted seeds. The bulk of the lignite consists of alder wood preserving the bark, offal from alders along with remains of other plants, all of the swamp-loving type—altogether, 37 species of flowering plants and 11 of mosses. The presence of pools in the swamp is indicated by the occurrence of *Valvata, Pisidium,* rare fishbones and elytra of beetles in the lignite; every plant indicates a temperate climate. A black loam, 13 feet thick, overlies the lignite: it is beautifully laminated and contains well-preserved remains of plants belonging to a cold climate, the arctic willow and birch. Fragments of plants belonging to a temperate climate occur in this loam, but their condition shows that they were derived from the underlying deposit. Above the loam are

[80] R. Dunlop, "Note on a Section of Boulder-Clay, containing a Bed of Peat," *Trans. Geol. Soc. Glasgow,* Vol. VIII., pp. 312–324.

[81] C. Reid, "The Relation of Paleolithic Man to the Glacial Epoch," *Rep. Brit. Assoc. Adv. Sci.,* 1896, pp. 400–415.

gravels and brick-clay, the latter containing freshwater shells, fragments of wood and paleolithic implements. These facts presented by Reid show that the peat has been converted by pressure into a lignite-like substance; the growth of the swamp was checked and the peat may have been exposed during the considerable period of changing climate, which led to the introduction of a subarctic flora. Direct superposition and conformability are certainly not evidence of continuity of deposition.

De la Harpe[82] saw a bed of peat at Lausanne, Switzerland, one meter and a half thick, underlying gravel and resting on marl. The peat is mixed with marl in the lowest part and the highest part contains some fine micaceous sand. Here and there in the black peat are occasional rock fragments, wholly isolated, as though one had cast them into the soft mass. Seeds, tree stems and branches, altogether decayed, were observed with, here and there in the upper part, a fragment of bark resembling birch. The underlying marl is without pebbles but has abundance of *Lymnæa, Valvata, Planorbis, Cyclas* and *Pisidium*.

Keilhack[83] saw a coal deposit near Lauenberg on the Elbe, with these relations, descending: (1) Upper clay, with shells; (2) diluvial sand, 15 meters; (3) coal bed, consisting of (*a*) fragmentary coal with stems and branches, (*b*) fruits and leaves, (*c*) moss; (4) clay; (5) diluvial sand with *Cardium edule*.

No additional details are given in the abstract. During the discussion, Hauchecorne and Beyrich insisted that the material is not coal but peat. Evidently the change in physical character was sufficient to make the relations somewhat doubtful. It is to be noted that the transformation is most advanced in the upper part and that the moss at the bottom appears to have undergone little change.

The deposits at Klinge, near Kottbus in Brandenburg, have given rise to much discussion as did that at Lauenberg. Keilhack[84] examined the great excavation and observed this succession, descend-

[82] Ph. De la Harpe, "Sur un gisement de tourbe glaciaire," *Bull. Soc. Vaud. Lausanne*, Vol. XIV., 1877, pp. 456–458.

[83] Keilhack, *Zeitsch. d. d. geol. Gesell.*, Bd. XXXVII., 1885, p. 549.

[84] H. Keilhack, "Der Alter der Torflager und ihrer Begleitschichten von Klinge bei Kottbus," *Zeitsch. d. d. geol. Gesell.*, Bd. XLIV., 1892, pp. 369–371.

ing: (1) Diluvial sand, 2 to 2.5 meters; (2) carbonaceous clay, 1.2 meter; (3) brown coal, peat-like, 1 meter to 3 decimeters; (4) clay marl, 3 to 3.5 meters; (5) peat, 45 centimeters; the upper part is Moostorf with seeds and reeds, while the lower portion has leaves, wood, seeds, rhizomes of *Nymphæa;* (6) Lebertorf with diatoms, 1.1 meter.

The Lebertorf is a lens-like deposit and is replaced in the southern part of the excavation by a meter of sand. Keilhack could not determine the age of the beds and maintained that the matter could be determined only by a boring. A. Nehring, in the discussion, held that the deposit is interglacial and probably equivalent in age to the Schieferkohle of Utznach and Dürnten. Credner[85] visited the same locality and obtained a section, evidently from another portion of the excavation. The peat is a single bed with maximum of a meter and a half, Number 4 of Keilhack's section being absent. The Lebertorf rests on clayey marl overlying sand. He thinks that the peat is post-glacial. In the following year, Potonié[86] summed up conclusions presented by H. Credner, H. Keilhack, A. Nehring as well as by other observers and discussed in detail the relations of the flora found in the Klinge deposits. This is distinctly diluvial. The succession is that of so many peat-filled basins, Lebertorf below, succeeded by peat in which are many erect rooted stumps, clearly *in situ.* The compression, due to weight of the overlying deposit, had so changed the appearance that Keilhack thought it brown coal with peat-like features, while Credner preferred to call it peat with resemblance to brown coal.

Weber[87] described two interglacial peat deposits, exposed during excavation of a canal from the Elbe to the Eider. One, seen where the canal emerges upon the Eider lowland, is exposed for more than 1,600 feet. The underlying material varies. The bed is in two divisions separated by sand; the upper one has suffered much from disturbance and is broken up badly, while the lower one is practically

[85] H. Credner, "Ueber die geologische Stellung der Klinger Schichten," *Ber. Ges. Wiss. Leipzig,* Bd. XLIV., 1892, pp. 385–402.

[86] H. Potonié, *Naturwiss.-Wochenschrift.,* Bd. VIII., 1893, pp. 393 ff.

[87] C. Weber, "Ueber zwei Torflager im Bette des Nord-Ostsee-Canales bei Grünenthal." *Neues Jahrbuch,* 1891, Bd. III., pp. 62 ff.

undisturbed, though at one end of the exposure it is curved upward so as almost to reach the surface. The succession in the lower division is clearly that observed in peat-filled ponds. The quartz sand on which the peat rests is without lime; by increase of humic matter, it passes gradually into peat with roots, leaves and fruits of *Potamogeton* and rhizomes of *Phragmites; Hypnum fluitans* appears at the top of this bottom layer, which passes upward into a thin layer of hard peat, mostly *Hypnum fluitans* accompanied by *Potamogeton* and *Phragmites,* the latter increasing above. Indeterminate fragments of beetle-elytra, pollen of conifers and *Betula,* with spores of *Hypnum* are abundant. This in turn passes very gradually into the third layer, 65 centimeters thick, very sandy brittle peat, containing abundance of twigs and roots of *Pinus sylvestris* with leaves, seeds and wood of *Betula verrucosa,* leaves of willow and wood of *Corylus;* there is much compressed wood, probably willow, some wood of fir and juniper was seen along with rhizomes of *Nuphar, Typha, Potamogeton,* etc. The highest layer is moss-peat, about a meter and a half thick, mostly *Hypnum hamifolius* with very little wood and rare *Sphagnum.*

The conditions are similar to those recorded in many recent peat deposits. But during deposition of the overlying sand, as shown by Weber's profile, the lower beds suffered much from erosion at one side, where the upper surface is jagged. The whole mass, including both divisions and the sand parting, has been subjected to severe lateral pressure, producing disruption of the upper division, upturning of both, so that the old peat deposit is almost united to the recent bog covering the present surface.

Molengraaff[88] reports that, in Borneo on the Mandai river, he saw thin layers of peat alternating with clay loam, the peat so compressed as to resemble brown coal. On the same river he saw thin beds of coal, evidently of recent origin; it is of poor quality, is laminated, lustrous, and has cleavage in two directions, breaking into parallelopipedons.

The deposits of Schieferkohle show similar features but on a much more extensive scale. Heer[89] examined the Schieferkohle at

[88] G. A. F. Molengraaff, "Borneo," etc., Eng. ed., p. 43.

[89] O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858,

Dürnten, where he found about 12 feet of coal resting on marly clay, with freshwater mollusks, and underlying about 30 feet of sand and gravel. The bed is divided by six partings of dark earthy material unfit for fuel and, in all, about 2 feet thick. The benches of coal are not alike. The lowest contains much wood and cones of *Pinus abies,* which are wanting in higher parts of the bed. In each of the upper benches, one finds, first, layers of moss felted into dense masses and pierced by reeds, which are followed by trunks lying in all directions, associated with roots, barks and pieces of wood, seldom very thick and always pressed flat. The annual rings are distinct though, at times, they have been distorted by the pressure. Some stems are wholly coaled as if by lightning. The tree trunks, as in peat, are embedded in a brown-black substance, derived unquestionably from herbaceous plants and originally forming a pulpy mass. This succession appears in every bench except the highest, in which reeds and mosses predominate, while stems of trees are comparatively rare. At Unterwetzikon, the lignite rests on marl with freshwater shells. At Utznach, there are two beds of lignite, 5 and 3 feet thick, separated by 16 to 20 feet of marly deposits. At Morschwyl, the Schieferkohle, variable in thickness, overlies and underlies marl and has a cover of 26 to 70 feet. It contains vertical stems, which in many cases extend into the overlying marl.

Heer's study of the plants proved that the resemblance of Schieferkohle to peat is complete. The trees are *Pinus abies, P. sylvestris* and *P. montana,* which are prostrate—they must have been overturned and been sunken in the bog. The wood is soft when first removed, but it hardens quickly on exposure; the bark is commonly present and twigs and branches, retaining the leaves, occur frequently. Other trees are yew, larch, white birch and sycamore. The last is represented by a few leaves in the lignitiferous clays. *Corylus* is not rare; *Menyanthus* is represented by abundant seeds and *Phragmites* abounds in the clay partings with *Scirpus; Sphagnum* and three species of *Hypnum* were obtained at Dürnten. The Schieferkohle and its partings contain abundance of mussels and swamp in-

pp. 7–11; "The Primæval World of Switzerland," London, 1876, Vol. I., pp. 29, 30; Vol. II., 155, 157, 160–163.

sects, while among the higher animals which perished in the bog are *Rhinocerus leptorhinus* and *Elephas antiquus*.

Deicke[90] looks upon the Swiss diluvial coal as a link between peat and brown coal; it passes over into both types. He discussed only the Morschwyl deposit as Heer had given details respecting those at Utznach and Dürnten. The coal lies in diluvium, 40 to 50 feet above the Miocene, is covered with drift-material, often 80 feet thick, and rests on ashen-gray shale or on a clayey sand containing small pebbles. The lowest coal layer encloses very many stems of trees, among which Scotch fir, red and white spruces, oaks, birches and others can be identified. All had been broken off and the fragments are from 8 to 12 feet long with, in some cases, a diameter of 3 feet. Except where the stumps are rooted, the stems are prostrate and show very marked compression. Birches are much flattened, the width of a stem being often 24 times its thickness. Conifers are less compressed, the width being rarely more than 4 times the thickness. Above this layer is a clay-shale parting, one foot thick, on which rests a coal composed chiefly of grasses and mosses, but containing many birches, some Scotch firs and rare spruces. In the clay shale and in the lower coal, Deicke found a great quantity of cones of Scotch fir, red and white spruce, rare cupules of oak, seeds of various grasses and wings of insects. The second bench of coal is succeeded by 4 feet of coaly shale, on which is another coal bed, averaging 3 feet and broken by shaly partings. The whole deposit thins away toward the borders. The coaly shale has nests of Schieferkohle and shows erect stems which, though fractured, are not compressed. Deicke recognizes Waldmoor conditions here; a forest was overwhelmed by mud, on which a Torfmoor developed. The trees died and were blown over; cones of spruce and fir remained in the mud and projected into the growing peat; Scotch firs, birches and the rest grew on the peat and were destroyed, when that material increased. Then came the influx of detritus and the resulting compression. Wood comprises about one tenth of the mass. When exposed to the air and sunshine, the lignite changes, loses texture and becomes Pechkohle; but complete change takes

[90] J. C. Deicke, "Ueber die Diluvial-Kohle bei Morschwyl im Kanton St. Gallen," *Neues Jahrbuch*, 1858, pp. 659–663.

place only in small stems and is rare when the diameter exceeds 2 inches. One end of a stem may be changed while the other retains its woody structure.

Klebs[91] described a coal which he saw at about 30 miles southwest from Königsberg: it underlies 15 feet of sand and overlies gravel, both of them diluvial. The section, descending, is: Black earthy coal, 1 foot; clear brown coal, 7 inches; dark, brown coal, 3 inches. The three benches are as sharply distinct as those of any peat bog or bed of stone coal. The whole thickness, including the thin partings, is 2 feet and the middle bench is harder than that above it.

Von Gümbel,[92] who had studied the Bavarian Schieferkohle in place, subjected to microscopical examination material collected at localities in Bavaria and Switzerland. He describes the Schieferkohle as partly loose, partly dense in structure, often like Pechkohle. It contains many flattened branches and parts of trees belonging to conifers, birch, willow, alder, in part lignite but at times already Pechkohle. Solution of caustic potash converts the less dense portion into a soft closely felted mass, in which the microscope shows, as predominating, parts of mosses and grass leaves. Tissue of wood appears rarely. The dense Pechkohle required treatment with Bleichflussigkeit (potassium chlorate and nitric acid) in order to bring out the structure. The densest material is that from Morschwyl, which shows the same plants as those in the looser or less dense portions along with an amorphous textureless substance like dopplerite. The density is due to this material, which he terms Carbohumin. Pollen, spores of mosses and lichens are not very abundant; cones of conifers are numerous in the coal mass, but are little deformed though they lie alongside of compressed stems. The inside of stems is yellowish and soft like decayed wood, but the bark zone has been converted into bright Pechkohle.

The Bavarian localities are typical. At Imbergtobal, near Sonthofen, a brown coal deposit is divided by partings of sandy marl, which are crowded with plant fragments and conifer needles

[91] R. Klebs, "Die Braunkohlenformation um Heiligenbeil," *Schrift. Ges. Königsberg,* Jahrg. 21, 1880, p. 82.

[92] C. W. v. Gümbel, "Beiträge," etc., pp. 135–138.

and have the features suggesting deposition by floods, which repeatedly overspread the continuously growing peat. They bear close resemblance to the partings seen in most coal beds. At Grossweil, near the Kochelsee, the Schieferkohle consists of easily separated layers of brown coal, twigs and wood fragments with others of leaves of grasses and mosses. The composition is made clear by solution of caustic potash. *Sphagnum* is the chief constituent of the moss layers; in others, pollen is abundant with small nests of fibrous peat and an alga. The deposit is distinctly one of peat and, at all localities, the coal-like and the peat-like portions pass gradually into each other.

Von Ammon[93] has given some notes respecting the distribution of Bavarian Schieferkohle. He states that a diluvial formation extends along the Loisach in an area of 9 by 2 kilometers between the Murnauer Moos and the Kochelsee. In this is embedded the coal bed mined near Grossweil (about 40 miles south-southwest from München), which he thinks is a forested Flachmoor of intramorainal age. It was opened at one time near Ohlstadt, where it is double and about 1.6 meter thick. At 10 meters above is another bed showing coal, 0.7 and 0.6 meter, separated by a parting of one meter. The coal is an earthy brown coal with inclusion of lignite. The Schieferkohle of Sonthofen varies much but is often several feet thick. At Josephsfelde, the thickness is from one to 3 meters; at Imbergtobal, there are two beds, three meters apart; the lower is from 2 to 5 meters thick and upper about 1.5 meter and impure.

Schieferkohle occurs in extensive deposits within Upper Austria, Styria and Tyrol. Lorenz[94] reported upon the conditions observed by him in the Hausrucker mountains of Upper Austria. The succession is: Fragmentary material, Kohle-Tegel system, Tegel, and the deposits appear to be conformable. The coal-marl system is from 100 to 150 feet thick and at most localities it shows three coal beds. The top and bottom beds are 7 to 8 feet thick, but the middle one is 12 feet. The lower beds are separated by a small

[93] L. v. Ammon, "Bayerische Braunkohlen und ihre Verwertung," München, 1911, pp. 9, 10, 63.

[94] J. R. Lorenz, "Ueber die Enstehung der Hausrucker Kohlenlager," *Sitz.-Ber. k. Akad. Wiss. Wien*, Bd. XXII., 1857, pp. 660–664.

interval, but the top bed is usually about 90 feet above the second. Each bed is limited above and below by coaly shale, 2 inches to 2 feet thick, which passes gradually into gray-blue marly clay. The lower beds are double, divided by carbonaceous shale. The parting in the lower bed is 2 inches thick, at 2 to 3 feet from the floor and is known as the "Hohl-lag"; that in the middle bed, known as the "Koth-lag," is almost paper-thin but is persistent. Besides these there occur occasionally in these beds layers of charred material, one third to one half inch thick and termed "Brand-lag"; they are of limited extent and cannot be regarded as partings. As the peculiarities of the beds convinced the author that these are composed of *in situ* plants, he explains the "Brand-lag" as derived from burned vegetable matter—that possibly the surface of the deposit had been ignited by lightning. After the fire had burned out, vegetation began anew. The mass of charred matter is enclosed in unchanged lignite, the separation being sharply defined.

Schreiber[95] has referred to two diluvial moors, one near Piehl in Styria and the other at Hopfgarten in Tyrol. That at Piehl is at 200 meters above the bottom of the present valley and is from one to one and a half meter thick. It underlies 150 meters of conglomeratic materials, and this great burden has so compressed it that it resembles brown coal; but Schreiber objects strenuously to the term Schieferkohle, preferring Schiefertorf, to distinguish it more sharply from the Tertiary brown coal. At Piehl, it rests on a marl; the lowest layer is brown hypnetum peat with loose texture, on which rests reed or rush peat, containing much earthy matter. Then follows a comparatively thick layer of Bruchtorf, composed chiefly of firs and birches. The highest layer is a sedge-moss peat and is thin at all localities examined by Schreiber. Overlying this bed is sandy clay, succeeded by moraine stuff and glacial débris. The Hopfgarten deposit overlies more than 100 meters of glacial débris, from which it is separated by clay bands. It was measured at three places and the thickness seems to be almost constant at about a meter and a half. The lowest portion is Riedtorf, with much mud and consisting mostly of sedges, though, here and there,

[95] H. Schreiber, "Vergletscherung und Moorbildung," etc., pp. 27–29.

reed and brown moss peat are shown. Well-marked Bruchtorf follows, composed mostly of Fichte, though occasional specimens of Scotch fir and birch were seen. According to Zailier, the sedge-moss peat follows, but Schreiber saw only a mere fragment of it. The deposit underlies moraine stuff. The Hopfgarten peat is less like coal than that at Piehl, though both are of the same age. Schreiber explains this by difference in the pressure.

Bursting Bogs.—Peat often remains a long time in the condition of "quaking bog." The floating mat constantly increases in thickness, so that at length it can carry large trees; but, under it, material from the bottom of the mat accumulates slowly and is pulpy. After long-continued rains, water may collect in such quantity as to break the cover and the black mud may be discharged upon lower levels. Lyell,[96] referring to the Solway moss in southern Scotland, states that its surface, covered with grass and rushes, shakes under the least pressure, the bottom being unsound and semi-fluid. On December 16, 1772, having been filled like a sponge during long-continued heavy rains, this bog swelled above the surrounding area and finally burst. A stream of half consolidated black mud crept over the plain with speed like that of an ordinary lava-current. The deluge covered about 400 acres. Tait[97] says that a very great part of the moss of Kincardine is a quaking bog, the peat being so wet as to be semi-fluid. During the process of reclamation, the support for the mass was removed and, on March 21, 1792, the peat began to run on the west side and the flow covered about an acre. On the same day in 1793, the flow was repeated and the peat mud covered nearly 12 acres of the cleared space. The extreme depth of the overflow was 8 feet.

The phenomenon is by no means rare. Lyell conceives that lakes and arms of the sea must occasionally become receptacles of drift peat; and in this way he would explain alternations of clay and sand with deposits of peat, found frequently on some coasts. This explanation would suffice only for some indefinite and insignificant deposits; it is difficult to conceive how the required con-

[96] C. Lyell, "Principles of Geology," New York, 1872, Vol. II., pp. 510, 511.

[97] C. Tait, "An Account of the Peat-Mosses of Kincardine and Flanders, Perthshire," *Trans. Roy. Soc. Edinburgh*, Vol. III., 1794, p. 278.

ditions could exist on great plains; lake deposits are too small to be important in this connection.

The Floor or Mur of Peat Deposits.—In regions where calcareous matter abounds, the floor of peat originating in ponds or lakes is apt to be the familiar lake marl, formed by *Chara* and mollusks, and containing other freshwater forms. Where calcareous matter is lacking, fine clay is the usual floor. Marl and clay are almost impervious; the impression has prevailed that peat grows only on a floor impervious to water.

But marshes and bog deposits may originate on rock of any sort, which is free from constituents injurious to plant life. The great Okefinokee Swamp of Georgia and the much greater Dismal Swamp of Virginia and North Carolina rest, in great part, on sand and in each the peat is thick. The buried peat of the Holland-Belgium-France area has mostly a floor of blue clay, though in many places it rests on sand. Typical freshwater peat may overlie marine sands, clays or limestones. The Carse land peats of Scotland, according to J. Geikie, have as the floor marine sands or marine clays; Moggridge found a similar condition in the Swansea excavations. Rohhumus or Trockentorf, so familiar in our forests, grows on bare rock; even granite may be the floor.

Davis[98] saw "climbing bogs" in northern Michigan, which had grown on smooth glacier polished granite. One, on an isolated rock hill, showed *Sphagnum* in spots, evidently thrifty and making a good growth, but most of the surface was covered with reindeer lichen, both in the open and under trees and shrubs. The peaty cover is thin and fibrous, with little moisture, but this supports the usual trees and shrubs, conifers with white birch and mountain ash as well as some heaths. A small island, with rounded glaciated surface and embracing about 3 acres, rises about 30 feet above Bubbling lake. The peat covering it is usually thin, about one foot but occasionally reaching 3 feet. It is coarse, spongy and brown, contains tree trunks, not thoroughly rotted, along with abundant partially decayed roots and stems of plants. When this locality was examined, the peat was so dry as to burn. The flora consists of the conifer-

[98] C. A. Davis, "Peat," 1907, pp. 264–269.

heath society. An indication of the mode in which peat formation began was observed on the north side of this island, where some spaces of otherwise bare rock were covered with a mat of *Sphagnum* with other mosses and lichens. As soon as these form their deposit, other plants obtain foothold and thenceforward accumulation of peat is continuous, if atmospheric conditions remain favorable. The growth of peat in a region where rain, at times, is wanting for weeks and where the soil is a coarse peat, only an inch or two deep and resting on a smooth rock, is due to condensation of atmospheric moisture in fogs. The plant society of this high, dry peat bed is very closely allied to that which characterizes the older and more mature portions of peat beds with a rock substratum—a confirmation of the belief that both are xerophytic habitats.

Chevalier's[99] observations in the Niger area, between 5° and 9° N.L., show that in that region, at 200 to 400 meters above sea-level, a sedge grows luxuriantly on the bare granite and gneiss, where it attaches itself so firmly as to resist the winds and the tropical rains. There, in hundreds of square miles within French West Africa, this sedge-growth has caused an accumulation of peat, 5 to 30 centimeters thick. The conditions are wholly unfavorable to increase of peat, as there is a dry season, during which the plants wither and the loss is accentuated by fires; yet the surface is covered with a fibrous material, described as very humic.

Ordinarily, however, some organic film is necessary, if the growth is to be rapid. As already stated, those engaged in the peat industry learned long ago that, if peat be removed wholly so as to lay bare the underclay, regeneration of the bog is very slow; but if a thin cover of peat be left on the floor, it is more rapid. The passage from the floor to clean peat may be gradual or abrupt. If the accumulation be in a pond, the transition may be marked by a faux-mur, showing laminæ of sand, clay or marl and peat, or it may consist more or less of the Lebertorf or Sapropel mud. In other types of deposits this faux-mur may consist of alternating peat and silt or sand, evidence of repeated flooding before the peat-forming plants gained the mastery. At times the passage is abrupt,

[99] A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *Comptes Rendus*, Vol. 149, 1909, pp. 134–136.

especially where expansion of the bog was by transgression, as is so often observed in plain deposits. The peat itself may be the mur for a new deposit, as where the drying of the upper portion invites invasion by a forest growth, to be destroyed by increasing moisture and return of bog conditions.

A very notable feature of the mur is the abundance at many places of roots and rooted stumps. This has been observed in all parts of the world, and the instances are so numerous that only a few need be cited as illustrations. Tait[100] states that the mosses described by him cover about 9,000 acres. The lowest part of the peat consists very largely of decayed wood, mingled with some black earth and occasional bunches of heather, better developed than those now growing on the surface of the bog. Innumerable tree trunks are at the bottom, lying alongside of their stumps, which, like the heath bundles, are still fixed in the clay. A considerable portion of the moss has been reclaimed by drainage and by complete removal of the peat. The trees at the bottom are oak, birch, hazel, alder, willow and, in one place, a few firs. In one clearing, 40 large oak trunks were found lying by their rooted stumps. These stumps, rooted in the clay, rise about 3 feet and are so little changed that they can be removed only with difficulty. But the stumps of other trees are so badly decayed that little can be said about them except that they are rooted in the underclay. Aiton[101] has remarked that the suggestion that peat deposits originated in forests is abundantly supported by the very frequent occurrence of trees or roots in the underclay. He never had examined a moss of any great extent without finding on its borders and where the peat had been removed "roots of trees still in the ground with their fangs extended as they grew." Along the river Aven, roots of trees are found under every moss "with their shoots firmly clasped into the earth, where they grew." Geikie[102] says that in many mosses, the tree stumps are of approximately uniform height and that the

[100] C. Tait, "Peat-Mosses of Kincardine," etc., pp. 228, 269, 271, 272.

[101] W. Aiton, "A Treatise on the Origin, Qualities and Cultivation of Moss-Earth," Glasgow, 1805, pp. 29, 33.

[102] J. Geikie, "On the Buried Forests and Peat-Mosses of Scotland," *Trans. Roy. Soc. Edinb.*, Vol. XXIV., 1867, pp. 379, 381.

peat grows over the trees which it has killed. A moss on the Isle of Man shows large trees, erect in place, with 20 feet of peat over them.

In 1837, the officers of the Ordnance Survey[103] reported that the lowest layer of fir trees overlies 3 to 5 feet of turf; but not so with the oaks, as their stumps are commonly found resting on the gravel or on small hillocks of gravel and sand, which so often stud the surfaces of bogs.

Reade[104] has shown that a railway cutting through Glazebrook moss exposed 18 feet of peat containing, in a thickness of 3 to 4 feet near the base, remains of trees and branches embedded in the peat. When the peat has been removed, one sees the oak and birch stools rooted in the underclay. A fine overturned tree with roots attached was exposed. It was 46 feet long and 3 feet in diameter just above the root.

Skertchly's[105] observations are equally to the point. In describing conditions in the Fenland counties of England, he says that trees are to be found in the peat everywhere, but that Digby and Bourn for the north and near Ely for the south are the most convenient localities for study. At these places, the trees rooted *in situ* are mostly oaks and are often of gigantic size; in not a few instances, the stems are 70 to 80 feet long and clear to the branch, distinct evidence of forest growth. In one moor he examined an overturned tree, which was 36 feet long with maximum diameter of 30 inches. Bark was preserved on the underside of the tree, but was carbonized and it crumbled into cuboidal fragments. In another fen, oaks are numerous and all are broken off at 2 to 3 feet from the ground, that is at the top of the peat. Some birches were here but only the bark remains; a few elms also, which were

[103] "Ordnance Survey and Report of the County of Londonderry," cited by R. C. Taylor, "Statistics of Coal," 2d ed., 1855, p. 169.

"It is a very remarkable fact, though very common, that successive layers of stumps and trees, in the erect position and furnished with all their roots, are found at distinctly different levels and at a small vertical distance from each other."

[104] T. M. Reade, "On a Section through Glazebrook Moss, Lancashire," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 808, 810.

[105] S. B. J. Skertchly, "Geology of the Fenland," pp. 158–162, 167.

recognized by their bark, the wood having decayed. Near Ely, he found a forest of yews, which penetrated the underclay into a thin layer of sand, in which their roots were spread out horizontally; thence the stems passed upward into the peat. In another fen, where the lowest peat is fetid and is known as "bears' muck," he saw a forest of oaks with roots extending into the Kimmeridge Clay below. The stumps, broken off usually at 3 feet from the roots, are associated with the prostrate stems.

Lorié[106] cites Belpaire père to the effect that in Zeeland trees rooted in the subsoil occur frequently in the peat. In discussing the conditions within an area of 1,400 square miles in Holland, Lorié says one finds there one or more peat beds covered with a greater or less thickness of sediment; these are autochthonous and contain stems of trees rooted in the subsoil. He has described a fossil forest near Fochtelos in the great Hochmoor of Smilde, Holland. Formerly, one saw there only a marshy heath; but the surface was lowered by drainage and by cultivation of buckwheat, so that the forest became visible. The trees are oaks with some aspens. The greater proportion of them have been broken off near the surface, probably after death, and the stems lie usually in a southwest to northeast direction. Those examined by Lorié appeared to be rooted in the peat but very near the bottom; but his guide maintained that all the fully exposed stumps seen by him were rooted in the subsoil.

Sections published in works on the Scandinavian swamps show the frequency of trees in the lower part of peat deposits, rooted in the underclay. Von Post[107] has published a photograph of the forest bed in the Tarnsjomoor, which had been exposed by removal of the peat.

Potonié[108] has discussed a great moor near Stelle, which is accessible in dry years. At one locality he saw, underlying 0.03 meter of sedge-peat, on which is one meter of sphagnum-peat, a forest

[106] J. Lorié, *Arch. Mus. Teyler,* II., Vol. III., 1890, pp. 424–427; II., Vol. IV., 1893, p. 183.

[107] L. Von Post, "Die Torfmoore Narkes," *C. R. XIIme Cong. Geol. Int.,* Stockholm, 1912, pp. 1282, 1283.

[108] H. Potonié, "Ueber Autochthonie von Karbonkohlen-Flotzen," etc., *Jahrb. d. k. preuss. geol. Landesanst,* 1895, pp. 25, 26: "Die Entstehung der Steinkohle," *Naturw.-Wochenschr.,* II., Bd. IV., 1905, pp. 7–9.

bed, which is filled with many large and small remains of firs, yews, oaks, birches and alders. The stems are mostly prostrate but with them are many stumps of fir and oak rooted in the bed. The same author, in a later publication, asserts that a Hochmoor may originate on a bed of sand if only there be sufficient moisture. To prove his position, he gives a reproduction of a photograph showing the floor of an extensive Hochmoor, which expanded by encroachment upon a forest growing on sand. The vertical stumps are exposed where the peat was removed.

The condition is familiar in the United States; G. H. Cook, N. S. Shaler, C. A. Davis, D. W. Johnson and others have considered the subject in detail. Davis has described conditions in the Pocosons or swamps on the coastal plain in North Carolina. But there are many peat deposits which did not originate on forested areas; those have no trees rooted in the soil below. There are others beginning in open area but expanding by transgression into a forested area; these have the rooted trees in one portion but not in the other.

It is unnecessary to cite evidence that the peat itself may be a soil for growth of non-water-loving trees. In every land, the peat deposits show successive forest beds, the trees being rooted in the peat and not penetrating to the underclay or subsoil. Numerous instances have been noted in preceding pages. But it is well to emphasize the fact that the opinion that plants have repugnance to thrusting their roots down into peat and that trees do not grow on peat, living or dead, is wholly erroneous. Plants disliking an acid soil certainly do not thrive on peat; but there are plants for which an acid soil is essential. Among these are some of the largest trees of America. That they have grown luxuriantly is certain, for in many of the extensive peat deposits in this country, the peat is commercially worthless because it is so crowded with stumps and stems. In many vast swamps of the coastal plain, a sounding rod cannot be thrust to the bottom and a similar condition has been reported from many places in the interior.

The Roof or Toit.—The roof of a buried peat bog may be as variable as the floor. It may be sand, clay or marl, freshwater or marine; the transition may be gradual, a faux-toit consisting of

alternating laminæ of peat and sediment; or it may be abrupt. Of course, the trees growing on the surface of the bog cannot escape when the bog is killed; if the floods be violent and the winds be high many of the trees, rooted in yielding soil, will be overturned; but if the covering material be conveyed by the ordinary winds or by an overflowing flood, the larger number of the trees will remain erect or at most inclined. Davis[109] has given an illustrative case. He has figured a standing tree trunk seen near Marquette, Michigan. The outer dune at that place had been cut by a storm only a few days before his visit. The waves had undercut the bank and the sand had slipped off, leaving a vertical face. Near the base was a layer of peat, one foot thick, filled with unchanged roots of shrubs and Norway pine. A partly decayed trunk of pine, rooted in the peat, its roots not extending below it, rises 8 feet through the overlying sand. That the accumulation resting on the peat was not due to a sudden overwhelming is clear, for at 2 feet above the peat is a layer of Norway pine needles, while from that to the surface, are irregular layers of sand with roots of trees, grasses and leaves of pine. The accumulation was slow enough to permit vegetable growth at several levels, but the stem did not break away, though the climate is moist. It is possible for trees to remain alive for a long time after a thick cover of porous material has been laid on the surface. Geinitz,[110] has described a forest of great oaks and beeches, growing on a bed of peat and covered in part by a dune. On the surface of the advancing dune, one sees, as it were, thick-stemmed oak and beech shrubs; but these are merely the upper portions of trees, still living, but in great part buried in the loose sand. At Morschwyl in Switzerland, where the overlying deposit is fine-grained, stems 6 feet high project from the peat into the marl above. Berry has described the buried bog on the Chesapeake waters, where the cypress knees pass into the overlying deposit. Seventy years ago, Lesquereux found leaves in the marl overlying peat and the partings of Schieferkohle have plant impressions. These leaves are transported material.

At several localities to which reference has been made, one finds

[109] C. A. Davis, "Peat," 1907, p. 253.

[110] F. E. Geinitz, "Nach der Sturmflut," *Aus der Natur*, Vol. IX., 1908, pp. 76–83.

a succession of peat beds, separated by clay, sand or marl, while peat is forming on the present surface. Some of these beds show trees rooted in the underlying material.

Soils of Vegetation.—The rocks intervening between peat horizons occasionally show what may be termed soils of vegetation, on which plants grew but no peat accumulated. Thomson[111] states that in making excavation for a naval dock in Bermuda, this succession was found, beginning at 25 feet below the surface: (1) Calcareous mud, 5 feet; (2) coral crust, 20 feet; (3) a kind of peat and vegetable soil, containing stumps of cedars in vertical position and the remnants of other land vegetation with remains of *Helix bermudiensis* and of several birds.

This old soil of vegetation rests on the usual "base rock" of the islands. Buried soils of vegetation have been noticed by all students who have visited the Bermudas. They are distinct at several places along the south shore where, in 1895, the dead cedar forest with trunks still erect protruded through the æolian beds, which in many spots were already covered with a dense growth of oleander and young cedars. No peat is found in the Bermudas except in "sinkholes" and estuaries; the porous rock permits rainwater to pass down quickly to tide level so that neither spring nor stream exists on the islands; but one finds buried soils with Helix and plant remains at various levels in the "sandstone" as the slightly consolidated æolian rock is termed.

Hilgard[112] saw, near Port Hudson on the Mississippi, brown muck overlying white or blue clay and underlying 93 feet of later deposits. This muck, 3 to 4 feet thick, contains cypress stumps, representing three, perhaps four generations. The stumps are rooted in the tough, somewhat sandy underclay. A similar deposit was seen at many places within lower Louisiana and usually several generations of cypress trees are shown. At one locality, huge stumps, 5 to 8 feet high, have their roots buried in a stratum of brown clay; the tops of

[111] C. W. Thomson, "The Atlantic," 1878, Vol. I., pp. 297, 298.

[112] E. W. Hilgard, "On the Geology of Lower Louisiana and the Salt Deposit on Petite Anse Island," *Smithson. Contrib.*, No. 248, 1872, pp. 5, 6, 7, 9, 11, 26.

the stumps are surrounded by similar clay but the middle portion is enveloped in yellow silt. A reddish loam is the superincumbent material to the surface. At about a mile below the Port Hudson locality, a deposit was seen, 30 feet above the stump horizon and resembling a river sandbar both in structure and contents. There, one finds no stumps but abundance of large drifted stems belonging to several species and some of them erect. These last, as Hilgard describes them, can be no other than "snags," which are even now only too numerous on sandbars along the river's present channel. At many places one finds living cypress swamps on the newer deposits.

The deep oil wells of the delta, according to Harris,[113] have proved that there are many muck beds in the Recent deposits of the delta region.

A section measured by Colenso[114] in the tin-producing area of Cornwall shows features not unlike those observed by Hilgard near Port Hudson: the succession is (1) Bed of river sand and gravel, 20 feet; (2) sand, containing tree trunks lying in all directions and mostly oaks, with bones of various mammals, red deer and whales, 20 feet; (3) silt or clay, 2 feet; (4) sand with marine shells, contains salt, 4 inches; (5) sludge or silt, contains recent shells and bones of mammals, 10 feet; (6) dark silt mixed with decomposed organic matter, about 12 inches, on which is a layer of leaves, hazel nuts. sticks and moss, 6 to 12 inches, this mass is apparently in place of growth and extends with some interruptions across the valley; (7) tinground, thickness varying according to irregularities of the underlying rock surface. Roots of trees are seen in this "ground" and on top of it oyster shells still remain fastened to some of the larger stones and to stumps of trees. The roots of oaks are in their normal position and can be traced to their smallest fibers, even as deep as 2 feet.

Here one has the soil of vegetation with its trees while, above it, are layers containing drifted logs and others of distinctly marine origin. It is worth noting that, at Sandycock in the same district,

[113] G. D. Harris, Geol. Surv. of Louisiana, Rep. for 1905, pp. 233, 240.

[114] J. W. Colenso, "Description of Happy-Union Tin Stream-work at Pentuan," *Trans. R. Geol. Soc. Cornwall*, Vol. IV., 1832, pp. 29–39.

Rashleigh[115] found 4 feet of peat in the upper part of the section, while the merely vegetable soil of Colenso's section is "solid black fen."

The presence of trees unassociated with peat has been regarded by some as evidence of allochthonous origin, as reforestation of an area after entombment of the peat seemed improbable. But reforestation is comparatively rapid on a new surface, provided only that there be moisture. During the great Missouri River flood of 1903,[116] the water, diverted from the channel by obstructions piled against a railroad bridge, swept over a wide area. Crops were ruined and a nursery field, near Topeka, Kansas, was covered with sand, which buried the young trees. But within three months, the naked fields were green with young cottonwoods, growing from seed blown in after subsidence of the flood waters. Even dunes, consisting of loose sand, become covered with vegetation and eventually with forest.

Reforestation is rapid even amid untoward conditions. Seventy-five years ago, the White Mountains of New Hampshire were covered with a dense forest, mostly spruce. Lumbermen denuded a very great part of the surface and their labors were supplemented by forest fires, which destroyed trees elsewhere. Where the soil was burned off, so as to be washed away and to expose the glaciated surface, nothing grew; but elsewhere the restoration was rapid. Plants of various types took prompt possession and prevented erosion. They were succeeded by birch and cherry, in whose shade the conifers grew. On the neglected farms of that region, one finds all stages of restoration, from pasture lots invaded by sturdy weeds to the forest of firs and spruces, which have overcome the birches. The conditions are similar in Ontario, as Miller and Knight[117] have shown. Their statement respecting one area is:

"Years ago, the area was visited by heavy fires which destroyed all but a few of the pine trees that were numerous and made the area important for its timber. On the part of the lake referred to, a few red pines and one or

[115] P. Rashleigh, "An Account of the Alluvial Depositions at Sandrycock," *Trans. R. Geol. Soc. Cornwall,* Vol. II., 1822, p. 282.

[116] H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," Bull. M, U. S. Weather Bureau, 1904, p. 62.

[117] W. G. Miller and C. W. Knight, "Pre-Cambrian Geology of Southeastern Ontario," Toronto, 1914, p. 18.

two white ones escaped the fire and were left as seed trees. Poplars have since grown up and now have a height of fifty or sixty feet or more. Back from the shore, where the seed has been blown, in the shade of the poplars, there is now a pretty growth of young pine trees, four or five feet in height."

In a letter, W. G. Miller states that the condition is familiar in many portions of Ontario.

Rock streams may still be seen at many places in the Allegheny mountains and in their path the forest has been removed. But even these coarse breccias become covered. Agnew[118] says that, when he returned by canal from Harrisburg to western Pennsylvania, he observed long stretches of stone-covered mountain side, bare of all vegetation from base to summit, the slope varying from 25 to 40 degrees. In later years, coming to Harrisburg to sit on the Supreme bench, he could find none of the naked spaces. The rocky surface had become covered with trees, the few remaining bare spaces being merely dots in the forest. The writer may add his testimony to the same effect. Rock streams are not wanting now in the Allegheny Mountains but they are not those, which were striking features in the scenery forty years ago; they are of later origin.

Forest growth may appear quickly after an area has emerged from marine conditions. One finds dense forests and great peat deposits directly on Post-Pliocene marine beds at many places along the Atlantic coastal plain of the United States. Darwin[119] saw on the island of Chiloe a bed of marine shells, the species being *Venus costellata* and *Ostrea edulis,* both now living in the adjacent bays. These were closely packed, embedded in and covered by a very black, damp, peaty mould, 2 to 3 feet thick, out of which a great forest of trees was growing.

It has been shown that forests on plains or even on rolling surfaces may bring about formation of peat deposits, but this does not occur always. Trees growing on peat have been entombed, others not associated with peat have met similar fate. River deposits have overspread extensive areas of forest, so that one finds in the rock

[118] D. Agnew, "Nature's Reforesting," *Proc. Amer. Phil. Soc.,* Vol. XVIII., 1878, pp. 26, 27.

[119] C. Darwin, "Geological Observations in South America," London, 1846, p. 28.

separating peat beds, trees singly or grouped, growing from an ancient soil with but small accumulation of offal about the stems. The buried forests of Oregon and Alaska, described by Newberry and Russell, are typical. Medlicott's[120] résumé of Ormiston's observations may be noticed in this connection, as they show how a forest, growing in an old soil of vegetation, may be succeeded by a marine deposit, while the stems remain erect. Excavations for a government dock were made on Bombay island off the west coast of India. In a space of about 30 acres, 382 trees and stumps were uncovered, of which 223 were erect. Some of the prostrate stems were without roots but others had been overthrown in place, for the roots were still embedded in the soil. The stumps are rooted in a thin soil of decomposed basalt and are surrounded by a stiff blue clay on which rests black marine mud, 4 to 5 feet thick. Stumps projecting above the clay into the black mud have been drilled by Teredo; in some cases the holes pass downward through the trunk toward the root and are filled with indurated clay. The trees are *Acacia catechu;* how far the forest extended is unknown, as no investigation was made beyond the limits of the excavation.

The opinion, that stems of trees would not endure while a considerable thickness of rock accumulates, is based on very serious misapprehension of the facts or on *a priori* reasoning. The writer has seen slender canes standing erect near the mouth of the Mississippi River, though they had been dead long enough to permit deposition of several feet of fine silt around them. Weed[121] has shown that the Yellowstone Park diatom deposits cover many square miles. A typical marsh is in the Upper Geyser basin, where the waters encroached upon the timber and killed the pines, whose bare gray stems stand upright in the marsh or lie half immersed in the ooze. The diatomaceous earth is sometimes 6 feet thick and the "gaunt poles of the dead pines stand in a white powdery soil, which is evidently a dried portion of the marsh mud."

[120] G. E. Ormiston, cited by H. B. Medlicott, Records Geol. Surv. of India, Vol. XIV., 1881, pp. 320–323.

[121] W. H. Weed, "Diatom Marshes and Diatom Beds of the Yellowstone National Park," *Bot. Gaz.,* Vol. IX., 1908, pp. 76–83.

Wright[122] has described the buried forest near the Muir glacier in Alaska. This was deeply buried under gravels, over which the ice extended at a later period. The ice retreated and erosion began, which eventually uncovered the forest. The trees are of large size, mostly like those now growing on the Alaskan mountains and are in a state of complete preservation. These are standing upright in the soil on which they grew, with the humus still about their roots. Some are exposed throughout while others are shown only in part. Many are broken off at from 5 to 20 feet above the roots; Wright thinks this fracturing due to cakes of ice, that being indicated by scars on the trunks. Russell,[123] writing about a portion of Alaska farther west, states that the Yahtse River, issuing as a swift current from beneath a glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but most of them have been broken off and buried in the deposit. Other streams east from the Yahtse have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and the stems are buried in prostrate position. Nordenskiold,[124] in discussing the distribution of trees in the Yenesei region says:

> "Besides these there are to be found in the most recent layer of the Yenesei tundra, considerably north of the present limit of actual trees, large trees with their roots fast in the soil, which show that the limit of trees in the Yenesei region, even during our own geological period, went farther north than now, perhaps as far as, in consequence of favorable local circumstances, it now goes on the Lena."

Resistance to Erosion.—The opinion, that trees would be uprooted and carried away by the strong current of a flood, is not well-supported as a generalization. The instances cited from Russell and Wright would seem to suffice in refutation and the writer has dis-

[122] G. F. Wright, "Ice Age in North America," 1889, pp. 57–59.

[123] I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Surv., 1893, Pt. I., p. 14, Pl. XII.

[124] A. E. Nordenskiold, "The Voyage of the Vega," p. 287.

cussed the matter somewhat in detail elsewhere.[125] But it may not be amiss to cite some additional evidence showing that floods and torrents are almost powerless against living vegetation. In the summer of 1895, the writer was marooned during three days by a flood on the Little Wichita River of northern Texas. The flood was widespread, affecting also the area of the Brazos River. It came abruptly, so that in a single night, the petty streams, flowing at 30 to 40 feet below the general level, filled their little valleys and overflowed; the parched area of the preceding day was covered with water more than hub-deep in many places. The current was extremely rapid; by mistake of the guide, the party were caught in it on one stream and narrowly escaped being swept away with the horses and the heavy conveyance. Within 2 miles of the city of Archer, the flood had invaded an extensive area, covered with trees and shrubs. Rapid outside, the movement was insignificant within this wooded area, the trees and shrubs, though not dense, being as efficient in checking the motion and in breaking up the current as is débris in a mountain forest. After cessation of rain, the flood subsided almost as quickly as it had risen. A ride of 60 miles over the area affected by it gave ample opportunity for studying the effect. The roads and sandy places were gashed and gullied; cultivated fields in the line of the torrents, one eighth to half a mile wide, were swept clean of the thin cover of soil, but where the surface was protected by grass the destruction was unimportant. Trees and shrubs, except those standing on loose material, were uninjured, while in extensive clumps of bushes there was no evidence of disturbance, aside from an accumulation of débris, deposited where the current first reached the plant-obstruction. The fierce current was powerless against trees, even against the clumps of bushes.

Reade,[126] writing of floods on the Senegal and Gambia Rivers, says:

> "If a boat was to be moored in the rivers to the top of an acacia tree just projecting above the water, you would find it afterward in the dry season hanging forty feet above your head."

[125] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 520–546.

[126] W. W. Reade, "Savage Africa," New York, 1864, p. 363.

After these violent floods have abated, the forests are seen practically uninjured by their brief submergence. The remarks by Harris[127] are in place here. The Hawash River rises in the Abyssinian highlands at 8,000 feet above sea-level. In the dry season, it can be forded easily but during the rainy season it is often converted into a fierce torrent inundating the broad valley, which is covered with trees and dense undergrowth, through which the explorer makes way only with great difficulty. When the expedition approached this river, it was very evident that there had been a flood, as "pensive willows that drooped mournfully over the troubled current, were festooned with recent drift, hanging many feet above the level of the abrupt banks." The condition was very similar to that observed by the writer in going by steamboat from San Francisco to Sacramento, almost 50 years ago. He was perplexed by the presence of clumsy débris in branches of trees at about 15 feet above the water. This marked the level of the floods.

The Ohio Valley flood of March–April, 1913,[128] was one of the most disastrous recorded. The damage to the towns of southeastern Ohio, as stated by Horton and Jackson, was almost 147,000,000 dollars, 36,000 buildings were flooded or destroyed and 220 bridges were carried away. The report is illustrated by 22 plates, showing conditions during and after the flood in several large cities, which suffered most severely. These show that trees in the streets resisted not only the current but also the débris carried by the water; houses and timber were piled around the trees and even the telegraph poles. One of the photographs gives ample proof that this was no gentle backwater overflow but a typically torrential movement.

The tenacity with which trees resist removal by floods is, to use a moderate term, remarkable. For many years the writer has ridden annually for more than 200 miles along the Connecticut River in June and September. In many places, trees cover the face of first terrace, extending frequently to within 18 inches from the line of low water. The terrace or "first bottom" is composed of uncon-

[127] W. C. Harris, "The Highlands of Ethiopia," Amer. ed., New York, 1844, pp. 94–96.

[128] A. H. Horton and H. J. Jackson, U. S. Geol. Survey, Water Supply Paper, No. 334, 1913.

solidated river drift, which where unprotected is attacked energetically by the current. The trees along the lower portion of the bank have roots almost horizontal, as the wet ground is little more than a foot below the collar. In very many cases the roots are exposed to a distance of two to three feet from the trunk, the loose material originally surrounding them having been removed. Several of these trees have been observed each year, during ten years the exposed portion has increased steadily, but the trees have continued to grow and apparently they are as solidly fixed as at first.

But in the sands under and over peat deposits as well as in rocks contemporaneous with such deposits, one finds logs, even tree stems with attached roots. Rivers undercut their banks, trees and plant débris fall into the water and are transported. Some of this material is carried to the sea, there to decay, but some is dropped in shallows or stranded on the river plain during subsidence of the flood, to be covered by deposits brought by succeeding floods.

Contemporaneous Erosion.—Little rivulets are seen in the smaller bogs, but great swamps, in which peat is accumulating, are more or less imperfectly drained by rivers with sluggish flow. The streams are subject to floods, during which they bring down more or less organic material mingled with plant débris. Much of this is deposited in the channelway and much of the rest is spread over the flooded portion of the swamp. Sometimes an obstruction dams the stream and diverts its course, leaving below the dam a stagnant pool, which in time becomes concealed by peat; but the story is revealed when a drainage canal is cut, for the half-filled channelway is shown by a "roll" in the underclay. The drainage system is often distinct in a buried bog. Lorié's[129] observations in the peat region of Holland-Belgium prove that the channels of large rivers have been filled with sediment and that these are traceable easily when the records of borings have been platted.

Banks of the intersecting streams are irregular, as plants spread out into the water, often becoming floating fringes. When the channelway is filled gradually by deposit of inorganic matter, the fringes are not torn away but are enveloped in approximately normal

[129] Cited in "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 617–619.

position, to be exposed as irregular strings of peat when laid bare by a drainage canal. If, however, the filling be abrupt and violent, masses of the peat are rubbed off to be embedded in the sand, while the adjacent portion of the bog is very apt to show crushing or folding.

Filled channels occur frequently in rocks associated or contemporaneous with the peat deposits. The Missouri and Mississippi Rivers have shifted the channels at many places and the abandoned "ox-bows" in numerous instances have been filled with material different from that of the banks. The rivers of the Gran Chaco of Paraguay and Argentina flow in constantly shifting channels, the older ways becoming filled to be exposed by a new change in direction of flow. A. Geikie[180] has described several cases of channels in the drift beds of Scotland, eroded and refilled during the Glacial period. Others have been noted by J. Geikie and by J. Croll.

Some Chemical Features of Peat.—It is well known that mature peat, when first taken out, is plastic; but when thoroughly dried it is no longer plastic. The same effect is said to be produced by freezing. It is evident, as said by v. Gümbel more than thirty years ago, that peat contains some substance, which is soluble in the fresh condition but is insoluble when dried. Microscopical study of mature peat shows that the minutely divided vegetable matter is accompanied by an amorphous substance, sometimes so abundant that the fragments appear to be cemented by it or even to be embedded in it. The earliest reference to this substance, known to the writer, is that by Reinsch,[181] who stated that in the Fichtelgebirge there are two kinds of peat, Rasen- and Pechtorf. Rasentorf occurs in thick deposits, 2 to 12 feet, but Pechtorf is in thin layers, as shown in his material from near Rautengrün on the left bank of the Eger river. The latter feels damp, almost greasy, is about twice as heavy as Rasentorf, has lustrous, brown-black surface and consists of roots embedded in an almost black substance.

Definite information respecting this material seems to be due

[180] A. Geikie, "On the Glacial Drift of Scotland," *Trans. Geol. Soc. Glasgow,* Vol. I., Pt. II., 1868, pp. 65 ff.

[181] H. Reinsch, "Ueber den Torf des Fichtelgebirge," *Journ. f. pr. Chemie,* Vol. XVI., 1839, pp. 489–495.

to Doppler,[182] who stated that he had received from Salzburg, in Tyrol, about 15 pounds of a black gelatinous substance, which had been obtained near Aussee in a peat bed, about 10 feet thick. It occurred in layers at 6 to 8 feet from the surface and it had been rejected as worthless. Schrötter,[183] who studied this chemically, ascertained that, dried at 100° C., it lost 78.5 per cent. of water and became a hard mass with conchoidal fracture and vitreous luster, resembling greatly the pitch obtained by distillation of coal tar. Dried at ordinary temperature, about 18° C., it parted with 66.22 per cent. of water. The wet gelatinous material lost 14.6 per cent. to caustic potash, equivalent to 68 per cent. of the dried material, but when dried, it lost nothing to the potash solution. Hydrochloric acid precipitated from this solution a brown substance which, dried, contains; Carbon, 48.06; hydrogen, 4.98; nitrogen, 1.03; oxygen, 40.07; ash, 5.86.

If ash and nitrogen be ignored the composition is, compared with that of cellulose,

Carbon	51.59	43.24
Hydrogen	5.34	6.30
Oxygen	43.03	50.56

The presence of ammonia is evident when a fragment is boiled with caustic potash. He recognized in this gelatinous substance simply a more than usually homogeneous peat, owing its gelatinous character to the great quantity of absorbed water.

At the same meeting, Haidinger[184] discussed the mineral relations of this material, to which he assigned the name, Dopplerit. It is amorphous, but thin sections, under strong power, show the presence of fine fibers in the mass. One of the pieces received from Doppler enclosed fragments of unchanged peat, in which *Phragmites communis* was recognized. Haidinger believed that this structureless peat is the beginning point of the whole series of changes, which up to that time had been wholly conjectural.

[182] Doppler; "Ueber ein merkwurdige in Oesterreich abgefundene gelatinöse Substanz," *Sitz.-ber. k. Akad. Wiss. Wien,* 1849, Bd. 3, Abt. 2, p. 239.

[183] Schrötter, the same, pp. 285–287.

[184] W. Haidinger, the same, pp. 288–292.

Von Gümbel[135] made an elaborate study of Dopplerit in 1858. He found that the Berchtesgaden dopplerite differs in some respects from that of Aussee. After drying in air, it gives off 12 per cent. of water at 100° C.; when heated to red heat in a closed vessel, it yielded 66.33 per cent. of non-coherent coke, retaining the form of the original fragments. The ash is but 1.67 per cent. of the dried material and consists mostly of lime. Treated with absolute alcohol, it yields a considerable quantity of resinous matter, which v. Gümbel thinks consists of two resins. The variability of composition at different localities leads him to believe that dopplerite is not a true mineral, but is merely a homogeneous peat and he suggested instead the term Torfpechkohle because of its resemblance to the Tertiary Pechkohle. The mode of occurrence at Berchtesgaden is peculiar, the succession in the pits being (*a*) Rasen- and Moorerde; (*b*) Specktorf; (*c*) Fasertorf; (*d*) Specktorf; (*e*) Fasertorf with roots; (*f*) gray marl; (*g*) calcareous pebbles. (*f*) is almost impervious to water. The Torfpechkohle is found chiefly between (*d*) and (*e*), but (*c*) contains much of it in irregular streaks. Two vein-like branches pass upward from the main deposit overlying (*e*) and continue through the higher benches into (*a*). He is convinced that the material was soft and that under pressure it flowed into crevices. This feature suggested that plant materials were softened as one step in the conversion into coal.

Kaufmann[136] received specimens of a lustrous black coal, occurring in a peat layer at Obburgen in Unterwalden, Switzerland. It agrees with dopplerite in all essential features. The material was from a Hochmoor, where it was found at 12 to 14 feet below the surface and in masses 6 inches to a foot thick, embedded in the black peat; but it often occurs as veins, streaks or nests. When fresh, it is gelatinous but it becomes hard on drying; it is odorless, has greasy luster and mahogany streak; softer than talc, it cracks under pressure. Examined under the microscope it is homogeneous,

[135] C. W. v. Gümbel, "Ueber das Vorkommen des Torf-Pechkohle (Dopplerit) im Dachelmoos bei Berchtesgaden," *Neues Jahrbuch*, Jahrg. 1858, pp. 278–286.

[136] F. J. Kaufmann, "Ueber den Dopplerit von Obburgen und über das Verhaltniss des Dopplerit des Torf und mineralischen Kohlen," *Jahrb. k. k. Geol. Reichsanst.*, Bd. XV., 1865, pp. 283–290.

but there are some fine granules, more or less transparent, and occasional traces of cell structure. Under water, dopplerite remains unchanged for years. Once dried, it is equally stable; when wetted again, it may soften so as to show the print of the finger nail, but no farther change appears after several months.

Muhlberg analyzed four specimens, three from Obburgen and one from Aussee the original locality. In all the carbon is higher while oxygen and nitrogen are lower than reported by Schrötter. The difference was enough to induce Muhlberg to make additional study. The material was treated with caustic potash and the dissolved substance was analyzed. It is richer than dopplerite in carbon. Kaufmann finds evidence that the varying composition is due to varying extent of change in the vegetable matter. Peat examined in thin slices shows sufficiently well the organic structure but it contains bright specks, soluble in boiling caustic potash; these are very rare in young peat but are abundant as nests in mature peat. This dissolved material acts as that dissolved from dopplerite. The proportion dissolved by caustic potash increases with the age of the peat, as shown by the following results of Kaufmann's experiments: 25 to 30 per cent. from peat directly under the living plants; 54 per cent. at 3 feet below the surface, loose; 55 per cent. at 6 feet below the surface, darker, fibrous; 65 per cent. 9 feet below the surface, coffee-brown, compact, comparatively heavy. Blackish-brown, heavy, compact peat with black pitch-like streak yielded 77 per cent.

According to Billingsley's[137] notes, the peat of the South Marsh, 3 to 15 feet thick, is accompanied by a pitch-like substance, which occupies the spaces between the vegetable fragments.

Zincken cites von Tschudi (1859) to the effect that dopplerite is found in Switzerland near Bad Gonten in Canton Appenzell, where, beyond the depth of 9 feet, it occurs in streaks up to 5 inches thick. Humus acid flows from this and hardens to Pechkohle; he cites J. W. Herz as authority for this composition of dopplerite: Water, 15.03; ash, 3.39; carbon, 57.47; hydrogen, 5.32; oxygen,

[137] Cited by H. B. Woodward, "Geology of Eastern Somerset," etc., 1876, p. 156.

36.25; nitrogen, 0.86. The material analyzed was air-dried; the ultimate composition as given is ash and water free.

Demel,[188] studying dopplerite from the original locality, found that it would not give up all its water at less than 120° C.; but this high temperature should not be prolonged, as decomposition begins quickly. His specimens contained no nitrogen, thus differing from those analyzed by Schrötter and Muhlberg. The ash varies little from 5 per cent. The carbon approaches that obtained by Kaufmann but is nearly 5 per cent. more than that reported by Schrötter, with also an increase of 0.4 per cent. in the hydrogen. He assigns the formula of $C_{12}H_{14}O_6$ to dopplerite. A large part of the mineral is soluble in caustic potash, from which it may be precipitated by acids. This precipitate has less hydrogen, the formula as determined by Demel, being $C_{12}H_{12}O_6$. The ash, 5 per cent., contains 72.67 per cent. of calcium oxide, equivalent to about 3.63 per cent. of the dried dopplerite, along with 12.02 per cent. of alumina and ferric oxide.

Von Gümbel in his later study, recognized the calcareous nature of the ash, which is snow-white; he thinks there may be a chemical combination of the calcareous and organic constituents.

Früh's[189] discussion was more elaborate than that by any one of his predecessors. He compared the features of dopplerite from many localities. It is present throughout some peats as brown flakes, one centimeter to a decimeter, giving a mottled appearance to the mass, which he terms Marmortorf. He found it only in Rasentorf (grass and sedge), or at the junction between Rasen- and Hochmoor (Sphagnum peat); that is to say, only in peat rich in water, a condition which favors ulminification. Dopplerite and peat are not separated sharply, there being always a passage zone. Evidently the dopplerite was fluid; it is associated frequently with a twig or root, along which it flowed; sometimes, it is in thin sheets; it may fill preëxisting cracks in the peat or in the underlying materials. The calcareous ash led him to believe that it is present in the Rasentorf because that thrives in calcareous water, whereas *Sphagnum* does not; at the same time, *Sphagnum* is convertible into

188 W. Demel, "Ueber den Dopplerit von Aussee," *Sitz.-ber. k. Akad. Wiss. Wien,* 1883, Bd. 86, Abt. 2, pp. 872–878.

189 J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 64, 68, 69–72.

dopplerite, for Früh saw dopplerite of sphagnum origin at the junction of Hoch- and Rasenmoor, where the water was very abundant. He objects very strongly to regarding the material extracted by caustic potash as the true dopplerite; he believed the mineral to be an ulmin product; the potash dissolves both ulmin and humin products. Dopplerite, according to Früh, is most abundant in the lower portions of a deposit, but the microscope detects flakes of ulmin-like material throughout the mature peat. It is well to recall here the fact observed by C. A. Davis in Michigan and by Dachnowski in Ohio, that *Sphagnum* is indifferent to the character of the water, limy constituents not interfering with its growth. Equally, Rasenmoors do not require calcareous waters, for the water of the Rhine and of the Meuse is thoroughly fresh. Kinahan, in 1861, referred to the tarry fluid which trickled from an Irish bog—evidently dopplerite.

H. L. Fairchild in 1881 and Lewis in 1882 described a dopplerite-like substance obtained near Scranton, Pennsylvania. Lewis's[140] description is the more in detail. This substance is in swamp muck at the bottom of 8 to 10 feet of peat and occurs in irregular veins. It is black and jelly-like when fresh, but on exposure becomes tougher and more elastic. Caustic potash dissolves it. Analyzed by J. M. Stinson, it proved to contain: Carbon, 28.989; hydrogen, 5.172; nitrogen, 2.456; oxygen, 56.983; ash, 6.400. The formula as determined from the analysis seemed to be $C_{10}H_{22}O_{16}$. There is little combined nitrogen as the quantity of ammonia is small.

Foster[141] studied a substance which appears to be very closely allied to dopplerite. The deposit is in northwestern New Mexico along a broad "wash," draining into the canyon of the Chaco River. Its existence was indicated first by a Navajo Indian, who said that wherever the Indians had sunk wells within an area, 10 miles long and of considerable width, they had encountered this material. The collector reported that normally it underlies clay and soil, but sometimes the clay is absent. At the first test pit, clay is absent and the

[140] H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1882, pp. 112–117.

[141] W. Foster, "A Remarkable Carbonaceous Deposit near Putnam, New Mexico," *Econ. Geol.*, Vol. VIII., 1913, pp. 360–368.

deposit, there liquid, was reached at 3 feet from the surface. It ran into the pit as rapidly as it was baled out. Four miles away on the same wash, a second pit reached, at 3 feet, one foot of clay resting on the deposit, more than 10 feet thick, the bottom not reached. At this locality, the substance has the consistence of gelatin, becoming denser with increasing depth. Dried, it is black, brittle, hard and, when powdered, resembles coal dust. In two trials, the material yielded 59.69 and 53.74 per cent. of water. Burned at a low temperature, it left 53.53 per cent. of ash, containing 3.03 of lime and 9.39 per cent. of soda. Ignoring the ash, the composition is: Carbon, 56.04; hydrogen, 6.76; nitrogen, 2.04; oxygen, 35.16, which approaches very closely to the composition of dopplerite analyzed by Herz, Kaufmann and Demel. The ash is apparently a silicate of aluminium and sodium; it is very finely divided and shows no trace of diatoms; Foster suggests that it may be chiefly disintegrated soda-feldspar. Jeffrey[142] examined the substance under the microscope; he found no trace of organic structure but crystalline mineral matter is present.

It is certain that peat contains an amorphous substance derived from the vegetable matter. This, originally more or less soluble, becomes insoluble when deprived of its water. The quantity is small in the newer peat but increases downward, being most abundant in the mature peat, where in many cases the vegetable fragments appear to be embedded in it. Its composition is variable, being dependent, apparently, upon the extent of chemical change in the plant material.

Composition of Peat.—In all works treating of general geology, one finds tabular comparison of the fossil fuels, based on the average of a great number of analyses. One may not deny the utility of an "average," when the averaged analyses are all from one mine on a bed of coal, the desire being to ascertain the general grade of the material as shipped. Yet even in that case, the defects in the method become painfully evident to the man, who having purchased on the basis of the average, receives coal from the less desirable portions of the mine. "Peat" is a generic term including products

[142] E. C. Jeffrey, letter of December 19, 1914.

of vegetable matter undergoing a chemical change which differ in composition according to the extent of that change, according to the nature of material and according to the conditions under which the change was made. Many matters have to be considered; if these be ignored, the comparison is worthless.

All writers on peat deposits have called attention to the fact that a notable physical change is observable as one follows the peat downward from the surface, the disintegration of vegetable matter increasing so that in the great mass of the mature peat, little trace of organic matter can be recognized by the unaided eye, while in many respects the lower portion bears much resemblance to brown coal. The specific gravity increases with this change. Mills and Rowan[143] state that young Hanoverian peat has the gravity of 0.113 to 0.263, whereas that of the maturer peat is from 0.639 to 1.039. The chemical change is gradual but more and more marked with increase of depth. Cornet[144] has given three illustrative analyses as follow:

	C.	H.	O.	N.	Ash.
Surface	57.75	5.43	36.06	0.80	2.72
Two meters and one half	62.02	5.21	30.67	2.10	7.42
Four meters and one half	64.07	5.01	26.87	4.05	9.16

The ultimate composition is calculated ash and water free. The extraordinary increase of nitrogen in the lowest portion may be due in part to the presence of some plankton materials. Jentzsch[145] says that in the province of Preuss, the peat deposits vary in thickness from a few inches to 17 meters. The composition of a peat used for fuel is, water free: Carbon, 56.90; hydrogen, 5.54; oxygen, 31.88; ash, 5.66. In his later publication he compares peat from several localities in the same province, thus:

[143] E. J. Mills and F. J. Rowan, "Fuel and its Applications," 1889, p. 18.

[144] J. Cornet, "La formation des Charbons et des petroles," Extrait de l'ouvrage, Geologie, T. III., p. 25.

[145] A. Jentzsch, "Die geognostische Durchforschung der Provinz Preussen im Jahre 1876," *Schrift. k. Phys. Okon. Gesell. Königsberg,* Jahrg. 17, 1877, pp. 120, 122; "Ueber die Moore der Provinz Preussen," the same, Jahrg. 19, 1878, pp. 128–131.

	C.	H.	O.	N.	Ash.
Surface peat................	49.90	5.80	42.80		3.50
Denser peat................	57.50	6.90	31.87	1.75	2.08
Dense peat..................	62.15	6.29	27.20	1.66	2.70

Mills and Rowan[146] have given analyses of surface and dense peat from three localities in Ireland,

	C.	H.	O.	N.
Surface peat.............	58.694	6.971	32.883	1.451
"	59.920	6.614	32.207	1.258
"	60.018	5.875	33.152	0.954
Denser peat	60.476	6.097	32.546	0.680
"	61.022	5.771	32.400	0.807
"	61.247	5.616	31.446	1.690

In the region whence these samples were taken, the growth of peat has been very slow during a long period, so that the surface peat, or rather, that from near the surface has undergone much greater change than that in similar position within areas where growth still continues. The same authors give results obtained by Woskresensky who analyzed Russian peat, which evidently came immediately under the growing surface; it contained about 41 per cent. of carbon with 54 per cent. of oxygen and nitrogen.

Mulder[147] analyzed fuel peats from localities in Holland and found the carbon varying from 59.27 to 61.05 per cent. and the oxygen from 32.50 to 34.71 per cent.

Zincken[148] has given the results of two analyses of Schieferkohle from Utznach, in Switzerland; the first is of the ordinary material, but the second is of a dense coal, hard, almost black and with conchoidal fracture;

	C.	H.	O.	N.
I.......................	55.27	5.70	36.84	2.19
II......................	56.04	4.70	36.07	2.19

146 "Fuel and its Applications," p. 20.

147 G. J. Mulder, "Ueber das arabische Gummi, die pectische Säure und die Zusammensetzung der Torfarten," *Journ. f. pr. Chemie,* Vol. XVI., 1839, p. 246.

148 "Physiographie der Braunkohle," p. 24.

If one may make a suggestion on the basis of these results, it would seem as though mere pressure has had little influence here, for the hard Schieferkohle of Utznach contains much less carbon than is found in some mature recent peats.

Von Ammon[149] has published an analysis of Schieferkohle from Grossweil in Bavaria, which, reduced to pure coal, shows: Carbon, 60.59; hydrogen, 4.86; oxygen and nitrogen, 34.55. The ash is 8.21. This coal, according to v. Ammon, is to be regarded as an earthy brown coal with inclusion of lignite ("bituminous wood"). It is of the same age as the Utznach Schieferkohle. C. A. Davis has given a long series of analyses from American localities, to which reference will be made in another connection. It suffices here to note than in four samples, with ash varying from 3.84 to 6.69, the carbon varies from 51.8 to 59.5 and the oxygen from 41.4 to 32.6, the determination being on basis of pure coal.

Peat, according to its age and its place in the deposit, may vary in carbon-content from much less than 50 per cent. in the upper portion to more than 64 per cent. in the mature portion, the calculation being on basis of the pure fuel. The more mature the peat, by so much the more it resembles brown coal in chemical and physical characters.

Nitrogen is present in all peats, of which analyses have been published. The analyses by F. M. Stanton, which have been tabulated by Davis,[150] make this clear for the United States. The quantity bears no relation to that of the ash. Peat from Leon county, Florida, has 4.28 of ash and 2.30 of nitrogen, while another from Lake county in the same state, has 21.94 of ash and 2.53 of nitrogen. One from Connecticut with 45.31 of ash has 1.92 of nitrogen, while another, with but 3.98 of ash, has 1.48 of nitrogen. Sulphur is always present, sometimes in sufficient quantity to be utilized. It and nitrogen are original constituents and are not due to the transported matter.

Study of ash in peat affords some insight into the conditions prevailing during growth. The mineral content may be original, that is, derived from the plants themselves, or it may have been

[149] L. v. Ammon, "Bayerische Braunkohlen," etc., 1911, p. 10.

[150] C. A. Davis, "Uses of Peat," pp. 186–203.

introduced by wind or running water. When the deposit has been protected from influx of silt, the ash may be less than 2 per cent. of the dried material; but there is every gradation from that percentage to shale, clay, or sand with merely a trace of vegetable matter. Such variations are commonplace in upland bogs and are illustrated by one in Ohio, recorded by Dachnowski, which had more than five times as much ash on the shallow border as in the deeper portions. Analyses published in European works are too commonly of material from localities where peat is dug, where it is of proved economic value; so that one is liable to suppose that peat with less than 10 per cent. of ash predominates. It would appear, however, that a much poorer grade of peat predominates, except where, in lowland areas, checking of streams at the borders causes dropping of the load or where a dense protecting fringe of plants, like the "cane brakes" of the Mississippi delta, act as filters. The analyses by Stanton in C. A. Davis's work are of samples from many localities in 8 states. Practically all of them were taken from previously unexplored deposits and, being collected according to the official method, they represent the whole thickness. A comparsion of the results shows that the peat from

24 localities has less than 5 per cent. of ash.
74 localities has less than 10 per cent. of ash.
28 localities has less than 15 per cent. of ash.
28 localities has less than 20 per cent. of ash.
28 localities has less than 30 per cent. of ash.
20 localities has less than 40 per cent. of ash.
43 localities has more than 40 per cent. of ash.

The lowest percentage is 1.53, which is less than that of the plants: only 98 samples show less than 10 per cent., while 147 show more, a vast preponderance of worthless material. The analyses, tabulated by Dachnowski,[151] are from 61 localities in Ohio; none is below 3 per cent., 14 are below 10 per cent., while 12 are above 20. When one considers that the samples, in all cases cited, were taken because the peat appeared to be such as might be utilized, it is evident that good fuel peat is only a small part of whole now existing.

[151] A. Dachnowski, "Peat Deposits in Ohio," pp. 366, 367.

The composition of the ash depends on the character of the plants and on that of the rocks over which the streams flow. Potash and soda are usually present, but in small quantity as their salts are soluble and easily removed. Lime, iron, alumina and silica remain. Mills and Rowan[152] have published 27 analyses by Kane and Sullivan, giving composition of ash from Irish peats. In these the lime varies from 12.432 to 45.981 per cent of the ash. Dachnowski gives analyses by J. W. Ames from 12 localities in Ohio, which show the lime varying from 2.210 to 4.529 per cent. of the ash. When one considers the notable quantity of certain conifers in peats, the low percentage of lime is a little perplexing; in most good peats it is only a fraction of one per cent. of the dried peat.

The action of various solvents upon peat was studied long ago by several chemists. Hunefeld[153] examined some loaf-like masses found in a peat bog near Borreby in Sweden. The proximate composition of the material was: Resin, 16.8; resinous matter like asphaltum, 40.0; wax, 2.2; coaly matter, with traces of humus, 38.0; oxide of iron with gypsum, 3.0. The material was supposed by him to be changed bread, which had been buried for about 800 years; but Berzelius objected that one cannot conceive how the constituents of bread could give a substance with this composition. Hunefeld studied numerous peats, treating them with alcohol and ether and obtaining 4 to 5 per cent. of resinous matter. There seems to be every reason to believe that his original work was correct and that he showed that resins, wax and asphaltum exist in peat, where there was no possibility that they were introduced from any external source.

Popular dread lest the draining of Haarlem lake might cause serious injury to the public health led Mulder[154] to examine the dense and the less dense peats separately, but by the same method. The peat was first boiled in water, which afterward was drained off, and the washed peat was dried and treated with boiling alcohol.

[152] E. J. Mills and F. J. Rowan, "Fuels," etc., p. 16.

[153] Hunefeld, "Nachtragliche Bemerkung über das Brod in Torfmoore," *Journ. f. pr. Chemie,* Jahrg. 1838, Bd. III., pp. 456–460.

[154] G. J. Mulder, "Untersuchung über die Harze des Torfs," *Journ. f. pr. Chemie,* Vol. XIX., 1840, pp. 444–453.

When exhaustion was complete, the peat was dried and treated with Steinöl. He obtained four resins, three of which are soluble in hot alcohol, but the fourth is soluble only in the Steinöl. These are from the denser peat. Analyses of the resins obtained from the less dense peats show that they are not the same, though closely related. The quantity of resinous material seems to be greater in the lower part of a deposit; and Mulder believed that it was formed during the process of Vertorfung and not derived from the plants directly.

Smith[155] utilized solvents in the study of some peats from Scotland. In his memoir, he summarizes the results obtained by Hunefeld, Reinsch, Mulder and Jacobsen. He treated his peats with naphtha and alcohol and obtained, as the result of several experiments, 6 per cent. of a solid resin, black and with waxy fracture. This material has: Carbon, 73.39 to 73.55; hydrogen, 10.78 to 10.49; oxygen, not given. Smith says that such wax can be obtained from peat by distillation, but the method of solution secures the crude product as it exists in the peat. He cannot accept the suggestion that the resinous material is due to chemical change but maintains that it must be traced to the original plants themselves; the increase in proportion downwards is due to the waste of more easily decomposed materials while the resistant resins remain unchanged; but in a more advanced stage of chemical action, the resins themselves are attacked and are removed in solution.

In considering these experiments and others of similar character, one cannot determine how much is resin and how much is paraffin material. Graefe's method of treating with benzol gives an approximate determination of the waxes. Von Ammon states that the Schieferkohle of Grossweil has 3.73 per cent. of material soluble in benzol; Kraemer and Spilker[156] examined a considerable number of peats, treating them with benzol and in some cases with toluol. They obtained from 3 to 8 per cent. of wax, the quantity in Hochmoors being less than in other types.

[155] R. Angus Smith, "A Study of Peat, Part I.," *Mem. Manch. Lit. Phil. Soc.*, III., Vol. V., 1876, pp. 303–331.

[156] G. Kraemer und A. Spilker, "Das Algenwachs und sein Zusammenhang mit dem Erdöl," *Ber. d. Chem. Gesell.*, 1912, Bd. 1, p. 1213.

It is wholly certain that the paraffins are present and that one is not compelled to go outside of the original plants to find a source for these or for the resins. The abundance of conifers leaves no doubt as to one source of the resins and waxes and these are characteristic of swamp plants. They are alike resistant to chemical change. The mode of occurrence of the New Zealand Kauri gum affords the necessary illustration for the resins. Penrose[157] states that this gum, a true resin, is a secretion of the *Agatha australis*, now living within an extensive area in New Zealand. The resin accumulates in large quantity on all parts of the tree and the bark, which peels off and is heaped on the ground, is saturated with it. The fresh exudations are unimportant commercially and the supply is obtained from the buried or "fossil" gum. This is found in regions now covered by the Kauri tree, in others whence the trees have been removed as well as in some where the only evidence of former forests is the presence of buried roots and other portions of the trees. At times, the Kauri forests have disappeared and have been replaced by those of other trees, the only proof of a former forest being the gum and the roots. That the antiquity of early Kauri forests is very great appears certain, for there are trees in the newer forests, which are supposed to be not less than 1,000 years old. At some localities, the gum is found in successive layers, separated by clays or sands, evidence of forests destroyed one after the other. The Senegal copal occurs under similar conditions. In many cases the resin-filled portions of the trees have been preserved, though all others have disappeared.

Distillation Products from Peat.—Lampadius published in 1839 the results of his investigation of products obtained from peat by distillation at and above the "cracking point." The experiments have been repeated many times and with similar general results. Two recent studies will suffice here. The Ziegler[158] process of producing coke from peat with saving of the by-products, has been tested on a commercial scale at some places in Germany. About 33

[157] R. A. F. Penrose, Jr., "Kauri Gum Mining in New Zealand," *Journ. of Geol.*, Vol. XX., 1912, pp. 38–44.

[158] C. A. Davis, "The Uses of Peat," U. S. Bureau of Mines, Bull. 16, 1911, pp. 128–142.

per cent. of good coke, containing 90 per cent. of carbon, is obtained from high-grade peat; though hard and compact, it retains the peat-structure. The tar, a mixture of the more readily condensed hydrocarbon compounds, rarely exceeds 4.5 per cent. of the dried peat, varies much in quantity and is a black viscous liquid. Subjected to fractional distillation, it yields, after separation of water, ammonia, light and heavy oils, paraffin wax, creosote and asphalt. The crude oils are said to be identical with those of petroleum in properties and appearance. The character of the tar water, containing lighter or less readily condensed compounds, depends in part on the character of the peat; the fibrous, less decomposed peats yield more methyl alcohol and acetic acid with less ammonia than those which are darker, thoroughly decomposed and structureless, which contain more combined nitrogen. This tar water contains ammonium salts, acetic and other acids as well as methyl alcohol.

The permanent gases vary with the character of the peat, the quantity of water and the temperature at which the coking is done, there being in every case a considerable proportion of air. The less decomposed peat gives the greatest quantity and the poorest quality. The variability in composition appears from two analyses, the first being from the Ziegler plant at Oldenburg and the other from that at Beuerberg; the percentages are in volumes;

	I.	II.
Carbon dioxide	27.4	15.5
Oxygen	2.2	1.1
Nitrogen	22.5	21.9
Carbon monoxide	8.6	20.4
Carburetted hydrogen	14.8	12.4
C_nH_m	1.0	
Hydrogen	23.6	28.6

The gas burns with a feebly luminous flame. Von Ammon[159] has published results obtained during destructive distillation of Schieferkohle from Grossweil, which is a well-decomposed peat with 60.59 of carbon. Two samples, each weighing one kilogramme, were tested, one retaining the woody structure, the second resembling earthy brown coal. The results are very different from those ob-

[159] L. v. Ammon, "Bayerische Braunkohlen," etc., p. 10.

tained by the Ziegler process. The coke is 23 to 24 per cent., the watery constituents vary little from 63 but the tar is from 1.24 in the earthy to 2.87 in the woody material. The earthy coal yielded 105.63 liters of gas whereas the woody material yielded only 97.55. The composition of the gas is

	I.	II.
Carbon dioxide	38.59	50.86
Carbon monoxide	16.80	10.60
Hydrogen	18.90	15.90
Carburetted hydrogen	0.60	1.10
C_nH_m	2.10	2.10
Oxygen	0.60	0.30
Nitrogen	22.60	17.70
Sulph. hydrogen	0.21	0.74

The tar-water of number I., the ligneous type, is acid, that of the other is alkaline. The amorphous, more changed material has less acetic acid and more nitrogen combined as ammonia, but the gas shows great increase in carbon dioxide with decrease of carbon monoxide. The results may not be wholly comparable, since the lignitic, woody material may contain some constituents in greater proportion than found in the amorphous peat; the former is coniferous wood while the latter was formed in great degree from plants of wholly different type.

Summary.—Before proceeding to consideration of the Tertiary coals, it is well to summarize the facts recorded in the preceding pages.

1. The area of Quaternary and Recent peat deposits is apparently greater than that on which carbon deposits were laid down during any preceding period of similar duration; yet it is but a small part of the earth's surface, for there are vast spaces on which no peat has formed since the Quaternary began, though much of the peatless regions has been forested.

2. Peat bogs vary in size from a few square feet to thousands of square miles. The smaller deposits are due to filling of pools, ponds or lakes by plant invasion, while the more extensive deposits, those on coastal or broad rivers plains, originated, certainly in some, probably in most cases, in small, isolated bogs, which became united

by transgression. These, though continuous superficially, are not strictly contemporaneous throughout. The buried deposits of Holland-Belgium-France are continuous with living bogs on the mainland; but the buried peat, in greatest part, is older than that now exposed, as evidently the marsh crept gradually inland during the subsidence. In like manner, the great deposits formed on plains show notable variation in thickness as well as in composition. The vast peat-covered plains of Alaska and Siberia have a contemporaneous top layer, but the underlying portions of the deposits are probably very far from being strictly contemporaneous.

3. The condition prerequisite to formation of peat is an abundant supply of moisture with sluggish drainage; this does not mean that alternating wet and dry seasons are necessarily preventive. If the supply of moisture suffice to keep the main mass moist, the loss during the dry season is more than made good by growth during the wet season, as shown by some tropical swamps. This condition of moisture depends greatly upon the topography, which determines the character and extent of drainage. Temperature is important as affecting rapidity of growth. In Spitzbergen, 78 degrees, North Latitude, peat covers considerable areas but the deposits are very thin, for the season of growth is brief and the temperature is always low. But the growth is much greater in the Alaska region to beyond the Yukon, where the plane of perpetual frost is within 6 to 14 inches from the surface. The atmospheric temperature during the summer is higher and the winter temperature is lower than in Spitzbergen as the climate is continental, not insular. In the cold regions, decomposition is less advanced than in lower latitudes and the accumulation is of vegetable matter rather than of peat, properly so-called. In the tropical areas, where the topography permits proper moisture conditions, it is evident that prolonged high temperature in no wise prevents accumulation but rather encourages it by favoring rapidity and density of vegetable growth. Koorders, Molengraaff, Harrison, Kuntze and others have described the vast deposits in tropical East Indies and South America. Harper, Hilgard, Lyell and others have described subtropical peat deposits in the United States, while many observers have written about the

temperate zone peats of North America and Europe as well as about those of the arctic and sub-arctic areas. In North America, the passage from subtropical peats of Florida to those of the subarctic areas is gradual; the plant-life changes, but the peat varies little in character. The fact is certain that in the tropics as in the temperates, peat accumulates where the necessary conditions exist and that it does not accumulate in either when those conditions are wanting.

4. Peat may be derived from any land plant, but ordinarily the flora contains many types. The constituent plants vary at the several horizons in a deposit, but for the most part the peat does not consist of any one plant or class of plants. Occasionally a layer consists of remains of a single species, but the occurrence is comparatively rare. The peat-making forms are not the same at all localities. In northern Europe, certain mosses, chiefly *Sphagnum,* are the important constituents in the upper layers, so also in some parts of North America; but there are considerable areas in both regions where mosses are either wanting or are wholly unimportant. Sedges have been the efficient peat-producers in much of the north temperate, even at some tropical and subtropical localities. But there is no limitation; conifers, palms, deciduous trees, mosses, sedges, in a word, any water-loving plant or any plant preferring a slightly acid soil will yield peat under similar conditions; the soft parts become a pulp but the harder parts change more slowly. More than 100 years ago, Al. Brongniart called attention to peat in Holland composed of leaves of conifers and Reinsch, almost 75 years ago, observed similar peat in Germany; the formation of peat from offal of oaks and conifers is a familiar phenomenon in the Rocky Mountain region.

In Tierra del Fuego, where conditions are subarctic, the chief peat producer, according to Darwin, is a sedgelike plant, *Astelia pumata;* in the Falkland islands, every plant is a peat-maker while at Chiloe, *Astelia pumata* and *Donatia magellanica* make up the mass of the peat. The Nile Sudd consists chiefly of sedges and grasses; in Florida, not only conifers of various types but also grasses and sedges contribute, and even the hyacinth has become important. But they all give peat; the sedge-conifer-moss peat of Germany is almost

the same in composition as the peat from Sumatra and other islands within the tropical regions. The differences in composition of peats from these widely separated localities are little greater than those observed in the several benches of any thick deposit.

5. The felted structure of the peat is not due to any special character of the plants, for it is present in forest litter. The extent of chemical and physical change increases downward in a deposit. At the top of a growing bog, one finds living plants, but within two or three inches, the mass consists of dead material, slightly changed in color but with small increase in percentage of carbon. Lower down, the organic structure becomes less and less distinct and, at length, the whole mass is, to the unaided eye, merely a pulp, in which are embedded fragments of wood and occasional leaves. The condition is described by both Darwin and Thomson for southern latitudes. The former, in writing of Tierra del Fuego, says that *Astelia pumata* constantly produces new leaves on the growing stem, while the older ones decay. Traced downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has been blended into a confused mass. Thomson says of the Falkland peat that roots of *Empetrum, Myrtus, Caltha* and sedges can be traced downward for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous, structureless mass. Examined under a glass, this pulp proves to consist mostly of plant remains, fragmentary and irregular in form. The unequal action of decomposing agencies causes this peculiarity of form, which might suggest to some that the plant remains had been subjected to attrition during transport by running water. But the material is of *in situ* origin, and all stages of change are distinct.

The several parts of plants are affected differently and not all plants are affected alike. *Hypnum* appears to be especially resistant, for layers of the almost unchanged moss have been found underlying a considerable thickness of pulpy material. The soft parts of plants are reduced quickly and the wood of most deciduous trees is reduced but little less rapidly. The wood of oak and conifers remains unaffected for long periods, practically the only apparent change being increase in hardness. The bark of nearly all trees

persists even after destruction of the other portions, so that the flattened bark becomes, as it were, an imprint on the pulp.

6. The stages of growth in peat deposits depend very largely on the original topography of the area. In the filling of water-basins, the first stage is formation of mud on the bottom. This may be calcareous, formed by *Chara* and mollusks, and may hold remains of water animals, pollen, spores, freshwater algæ and vegetable remains of other sorts, floated in by streams or blown in by the wind. If streams carry detritus and the water have low calcareous content, the bottom is covered eventually by fine silt with similar organic content; but if the pond be free from influx of detritus and calcium salts, the first deposit is a mud consisting of remains of aquatic animals, freshwater algæ with spores and pollen blown in by the wind. This is the Lebertorf stage, the Sapropel stage of Potonié. This material, in some cases, increases with great rapidity, and the water, at length, becomes so shallow that certain types of aquatic plants take root and the formation of normal peat begins; first, the plants rooting under several feet of water; then reeds encroach and the rushes and sedges advance to form a floating cover, on which shrubs and even trees take root along with ferns and, in many localities, eventually *Sphagnum*. The trees advance, conifers first, to be followed by deciduous forms of the forest type when the surface becomes dry to a depth of a foot or more. Throughout, one finds abundance of spores and pollen grains, and occasionally a lens of Lebertorf occurs, marking the site of a pool or pond in the growing mass. This, in a general way, is the succession as worked out by the early observers and confirmed by all students during the last third of a century.

The succession may differ somewhat in deposits formed on plains bordering great rivers or on coastal areas. These begin frequently, perhaps generally, in small, shallow ponds, caused by local obstruction of drainage and expanded by transgression, which led to union of many small deposits. The Lebertorf stage could exist in the original small spaces but not in the newer portions formed during transgression, except where local ponds originated in the peat.

7. The accumulation of peat has been continuous in few locali-

ties; even small deposits show pauses like those which characterize those of greater extent. Many times a cyclical order is distinct and the deposit is divided into benches. The process was interrupted again and again, so that the surface became dry enough for growth of trees, not merely of conifers but, in some cases, even of deciduous trees of forest type. Sometimes such pauses were of long duration as is shown by the age of the trees. The forest growth was frequently very dense, for the peat is loaded with stumps and broken stems. A considerable proportion of the trees were overturned, perhaps by the wind, and sank undecayed into the soft pulp. The moister conditions returned, the trees were drowned and peat growth was resumed. This succession may be repeated several times in a single deposit.

The benches may pass gradually, the one into the other, or they may be defined sharply by partings. At times the parting consists of Torffaserkohle or mineral charcoal, mingled with extremely fine mineral matter, the residuum on the surface of peat long exposed to oxidation. Such partings mark a period of dryness without invasion by forest, during which the peat wasted. But partings of clay, sand or marl mark invasion by water carrying detritus. After a period, long or short, the surface is again covered with shallow water and peat making is resumed, the parting serving as mur for the new accumulation. The parting of Torffaserkohle and ash may be continuous with the thick parting of transported material, so that when peat making has been resumed over the latter, the process would extend over the thin parting of wasted peat. It is important to bear in mind that the thin parting is more than equivalent in length of time to the thick parting. The new peat, expanding by transgression, required a period for advance; the peat underlying the parting of transported material may be strictly contemporaneous throughout, except that the upper part is represented by the thin parting. A thick cover of detrital matter may bring accumulation finally to a close in one portion of an area while growth continues in another. Sand dunes in some localities within the United States have covered bogs of small size so that no farther increase was possible; but in the Baltic region, as shown by German and Scandinavian geologists,

dunes have covered great portions of the peat area, while other great portions have remained uncovered and in continuous growth.

8. Expansion of peat deposits by transgression has been observed in all parts of the world. Trees, still standing but killed by advancing marshes, have been described by several writers in the United States, and the process of covering the stems has been made clear in preceding pages by citations from Scottish authors. In many deposits of wide extent, the fact of transgression becomes evident only after removal of the peat for fuel or during reclamation. The stumps of the invaded forest are laid bare, their roots still fixed in the mur of the deposit, while their broken and shattered trunks are prostrate in the peat, which accumulated around the trees and destroyed them by preventing aeration of the roots. Many of these great deposits have no trees rooted in the mur in some portions, while those are abundant in other portions. The stumpless spaces mark the places where the bog originated; those with stumps and prostrate stems mark expansion by transgression on the forest area. These features are characteristic of peat deposits in the British Isles, the Netherlands, France, Germany, Sweden as well as of those East Indian swamps which have been reclaimed for agricultural purposes.

9. The effect of pressure on peat is to render it so similar physically to brown coal that the contrast with normal peat is very great. Forchhammer, Jentzsch, Nilson, Lesquereux, Goeppert and Schreiber have written in detail respecting this matter and incidental observations are to be found in writings by other authors. Even the long-continued pressure of peat itself in a deep deposit has much the same effect on the lowest layers.

10. Peat contains introduced materials of various kinds. Logs and stumps are not of these; they are merely the more resistant parts of peat-making plants, embedded in pulp from less resistant portions. Fragments of rock, sometimes angular, sometimes water-worn, have been reported from a few localities. The comparative infrequency of references may indicate rarity of occurrence, localization within the peat or the indifference of observers. The facts available are so few that any suggestion as to the origin of these fragments would be worthless. Often, there is much silt; at times, one

finds pockets of sand or clay, even of freshwater limestone. The limestone cannot be regarded as extraneous, for in all probability it was formed *sur place* in ponds within the swamp; but the other materials are of foreign origin and indicate more or less frequent flooding by detritus-laden water. In considerable areas, the quantity is so great as to render the peat worthless; in others the material is localized, as in bogs of lake or pond origin, where the peat on the borders is commercially worthless, while midway in the basin it is almost free from mineral admixture. The several benches of a peat deposit often differ notably in mineral-content, showing variations in conditions during formation. Bones of mammals, shells of freshwater mollusks, remains of beetles and other insects are of common occurrence. Peat deposits have yielded the best specimens of Pleistocene mammalia; domestic cattle are often mired in swamps and whole troops of armed men have perished in Scottish swamps during flight after battle.

11. The floor or mur of peat deposits may consist of any mineral material not injurious to plant life. Ordinarily, in swamps originating in ponds, it is composed of more or less nearly impervious stuff, clay, lake marl or Lebertorf mud. Where a deposit has increased by transgression, the mur may be shale or even sand; but in the latter case the immediate floor is apparently the cover of forest offal, the underlying sand having been rendered more or less nearly impervious by humic acid derived from the organic cover. The characteristic feature of the mur is the presence of roots belonging to peat-making plants. In original localities, where peat was formed in open areas, the roots are those of reeds, rushes water-lillies, etc.—the Rohrrichtboden of German writers being a familiar condition. Where the deposit originated in forests or encroached upon them, one finds in the mur a tangled mass of roots, oaks, conifers, alders, birches and other plants, from which the stems very commonly pass into the peat. These stems rarely extend beyond the peat cover and they are broken off at practically the same level. Where the deposit consists of several benches, each becomes in turn a mur for the next, and roots are distributed in the peat-mur as in the original clay or other mur; in each bench the stumps are cut off at or below the top of the peat.

It is seemingly probable that the pause at the close of the bench-formation was long enough to permit complete decay of exposed parts of the stems. Usually, however, the decay was complete before the end of the peat-forming period and one generally finds the upper part of the bench continuous over the tops of the stumps. The durability of stumps and of some woods is remarkable even when they are exposed, and it is much greater when they are buried in peat or in loose material containing much moisture. But decay of the wood is much more rapid than that of the bark; a stem may become hollow and the space may be filled with silt or sand holding leaves or remains of small animals, as Lesquereux, De la Beche and Potonié have shown.

12. The roof or toit of a peat deposit may be as variable as the floor. As in the latter one finds usually a gradual passage from the rock to the peat, giving a faux-mur, so on top one finds similarly a gradual passage from peat to rock, a veritable faux-toit. In this, one recognizes frequently roots, stumps and prostrate stems, remains of the forest which covered the peat. But the forest was not always present; the deposit was buried before the cycle had been completed, so that one finds, mingled with the silt or sand, leaves only of upland vegetation. The roof may be of freshwater, marine or æolian origin, it may be sand, clay, marl or limestone; the calcareous beds accumulate slowly, the others slowly or rapidly. Erect trees, rooted, are found in the roof material, but unlike those in the peat, they are not all broken off at the same height. Where engulfing material is æolian sand not deposited continuously, the trees may adjust themselves to the conditions and a long period may elapse before their death, so that the buried forest may remain in normal position and the erect trees may penetrate a notable thickness of rock, as in the Baltic provinces. When the material has been transported by running water, the accumulation may be less rapid, but enough so to kill the trees by rendering the cover too wet. The erect stems may be of any height, from mere stumps to a score or more feet and they may be surrounded by rocks of various kinds, sands or clays, in mass or in alternating layers.

Under the term "roof" may be comprehended all rocks between

one peat horizon and the next. Very often one finds in this interval alternation of land, freshwater and marine conditions. The immediate roof may be clay succeeded by sand, both of freshwater origin, but on these may rest sand or marl with shells of familiar marine mollusks. The sands frequently contain transported remains of plants, in some cases trunks of trees, prostrate, inclined or even approaching the vertical and accompanied at times by bones of various mammals, with land, freshwater or brackish water shells. The plant remains usually differ from those in the peat, and they appear to have come from undermined banks of rivers. An interesting and by no means uncommon feature is the occurrence of "soils of vegetation," bearing remains of forest growth, there being an accumulation of forest offal about and between the stumps. These mark exposed surfaces on which trees grew but where swampy, peat-forming conditions did not prevail. Erect as well as prostrate trunks are present, all enveloped by the mass of sand or clay which buried the old soil.

13. All areas in which peat accumulates have imperfect drainage; the streams are usually sluggish and are easily diverted. The peat, at times, encroaches on the channelways and eventually fills them. This condition is recognized readily when the section is exposed in excavations for reclamation canals, for the silt or sand forms a "roll" on the bottom, narrowing upward and covered by peat. Sometimes a new channel is formed during a flood and the sand-laden water tears away the peat, sometimes to the bottom, giving a "roll" in the roof, which narrows downward. Similar conditions are not rare in interval rocks between peat horizons, buried channelways being of frequent occurrence. This contemporaneous erosion marks the existence of land surfaces.

14. Plants growing on peat show great adaptability to changing conditions. Birch requires that the roots have free access to air, but C. A. Davis states that he has seen birch making thrifty growth, where the roots had been covered during two growing seasons by a foot of water. Shaler described the habits of *Taxodium distichum,* the familiar cypress of our southern swamps. Where the region is dry, the plant shows no peculiarity of root structure; but

when it grows in a swamp, where the roots are in the saturated peat, covered with water, it puts forth the curious "knees," which project beyond the water surface and provide means for aeration. If the water-level be changed abruptly, so that the knees are submerged, the tree dies, as appears in the New Madrid area, where during the earthquake of 1811, the land sank and the swampy area became a lake. *Nyssa* is provided with an equivalent protection for aeration. Conifers are found far out on the wet sedge-mat, which floats on the surface of a lake; but they grow slowly amid the untoward conditions and usually are overturned by the wind before attaining great size, as their roots are radial and very near the surface. Capp's observations respecting conditions in the White river district of Alaska are thoroughly illustrative. Peat as a soil is not repugnant to plants. The acid character of new peat is offensive to most of our deciduous trees and to many other plants; but many others, among them majestic trees both conifer and deciduous, thrive best on the damp acid material. When a bog ceases to grow, the thin upper layer becomes freed in considerable measure from the acid and the moisture; usually it is occupied quickly by the ordinary forest trees of the region, though the saturated peat may be only a foot below. The roots of these trees are radial, creeping near the surface.

15. Peat, deprived of moisture and exposed to the air, quickly undergoes change. The soluble cementing material becomes insoluble, or is removed, the mass becomes pulverulent and is apt to be swept away by the wind. The vast reclamation works, which have converted swamp areas into agricultural land, have exhibited the changes on a grand scale. The natural conclusion seemed to be that peat has been formed only to waste away. But this is an error. Peat has been formed to be preserved. Peat deposits in Scandinavia, Germany and Great Britain have existed since the Glacial period and in not a few localities they are still growing. But the growth has been interrupted many times and for considerable periods; the surface was exposed, but not long. Under ordinary conditions, shrubs and trees advance as the peat surface dries and the Waldmoor or forested bog is protected from waste. Under

other conditions, the bog may be covered by mineral materials, as on the lowland of Holland, Belgium and France, and waste by oxidation is prevented. By one method or the other the peat is preserved indefinitely: by the former method, the continued increase of peat is assured in most cases, as the forested surface again becomes marshy and peat production is resumed, to end again in a forest. This cycle has been reported again and again from peat bogs of northern Europe. The thickness of a deposit depends, other things being equal, upon the period of growth; the thickest deposits reported are those in Alaska and in tropical and subtropical regions; in those regions climatal changes have been comparatively small since the Quaternary began.

16. The composition of peat depends ordinarily upon its age, that at the bottom of a deposit not only approaches complete disintegration, so that to the unaided eye it shows no trace of organic structure, but it also is far advanced in carbon-enrichment. Yet peat from neighboring localities, where conditions seem to have been similar, may show great dissimilarity in composition; one finds strange contrasts even in the benches of a single deposit, for some may be far advanced while others consist of almost unchanged plants. This study is not concerned with the processes involved in conversion of vegetable matter, so that one must be content with the statement that some benches were buried when those processes had been checked at an early stage and that apparently no progress has been made since burial. The carbon in peat may vary from little more than 40 per cent. in the topmost layer to 49 in the next—the first used for fuel—and to 64 in the bottom portions. But in bogs where the surface growth has ceased or has been unimportant for a long period, the part immediately below the surface may have 58 to 60 per cent. Oxygen shows similar variation; there being 36 to 40 per cent. in the highest part used for fuel while the oldest, densest portions may have only 26 or 27 per cent. The ordinary fuel peat has from 57 to 64 per cent. of carbon. Density is not evidence of advanced change; the dense, hard, black Schieferkohle of Utznach, compressed by the heavy cover, has 56 per cent. of carbon and 36 of oxygen.

The ash is extremely variable even in a single deposit. Only a small proportion of the peaty material on the earth's surface is good enough for fuel and a great part of that now forming is little better than carbonaceous shale, with 25 to 50 or more per cent. of mineral matters. At times peat is found with less ash than should be expected, less than that contained in the original plants. Solution has made possible the removal; potash and soda are usually present, but in small quantity, the greater part having been removed. Lime, iron and alumina are always present, though in exceedingly variable proportions, this being due perhaps to the character of the drainage area—but this suggestion is not always satisfactory.

At many localities, the organic acids in solution have become a cementing material, more or less disseminated throughout the structureless mass, dopplerite in peat, Carbohumin in Schieferkohle. In peat, it is gelatinous, but after the water has been removed it is hard and insoluble. It has reached the latter condition in Schieferkohle.

Resins, waxes and paraffins exist in peat, from which they can be extracted by solvents. They have been derived directly from the plants; there is no reason to believe that they were formed during the conversion into peat or that they were introduced from an external source.

The Tertiary Coals.

Tertiary coals, of the ordinary types, are termed Braunkohle in Germany and Austria but in France and English-speaking countries they are known as lignite. The passage from peat to brown coal is extremely gradual and occasionally, as indicated on preceding pages, determination of the relations is merely a matter of personal equation. In Europe generally the complex group known as brown coal has abundant points of similarity distinguishing it from the Palæozoic or "stone" coals, so that, as Mesozoic coals are comparatively unimportant, the effort there has been to ascertain why brown coal and stone coal are so unlike and to discover reasons why the former could not be converted into the latter. But in North America the condition is wholly different, for coals of all types from wood-like lignite to bituminous, even to anthracite occur at

times within a single district, in a single bed or even within the limits of a single estate. The passage from one type to the other is so gradual that chemists and geologists of North America have labored to discover some means of distinguishing them. The problem is no longer one of merely abstract or scientific interest; it is of the utmost practical importance, since within a vast area the only source of supply is in the Tertiary and Upper Cretaceous deposits. The effort is to determine distinctions which will be available for both the seller and the purchaser of fuel.

In most works, the characteristics of brown coals are given definitively. Though in mass the color may be black, yet the powdered material has a brown tint; the content of water is considerable and air-dried specimens retain 10 per cent. or even much more, so that brown coals have been termed hydrous; jointing or cleat is wanting or at best ill-defined; the water in air-drying escapes through shrinkage cracks or along bedding planes and the coal falls into small fragments; brown coals do not coke; solution of caustic potash attacks brown coal and acquires a reddish or brownish tint; brown coals contain more carbon than peat but notably less than the stone coals.

These features are characteristic of brown coals in general but they are not wholly distinctive. Some brown coals yield a black powder and some Carboniferous coals give a brownish powder; many Carboniferous coals retain more than 10 per cent. of water and there are Tertiary coals with very much less; there are Tertiary coals with very distinct cleat while there are Carboniferous coals in which cleat is very indefinite; there are Carboniferous coals in extensive areas whose included water escapes along the bedding planes and the coal breaks first into slabs and then into small fragments; a very great proportion of Carboniferous coals do not cake while there are Tertiary coals which yield good coke; caustic potash solution attacks many Carboniferous coals; the carbon-content is not definite. In fact, the passage from brown to stone coal is as gradual, chemically, as that from the growing layer of peat to brown coal.

A proper examination of this matter will be in place only after study of the Palæozoic coals. For present purposes, the classifica-

tion by Hoffmann[160] must answer. He recognized a gradual change in the chemical and physical character of the upper Mesozoic coals from east to west within the Bow and Belly river region of western Canada. In the eastern strip of that district, the fuels have all the characteristics of lignite (brown coal) ; those of the middle strip are intermediate between lignites and true coals, the latter being found in the western strip; while in the mountains, farther west, anthracite occurs. All belong to the same general horizon in the Upper Cretaceous. Reasoning from the series of analyses which he had made, he grouped the fuels into lignites, lignitic coals and coals. Lignites are fuels which, on exposure to the air, tend more or less to disintegrate and to fall to pieces; they all communicate a deep brownish red to boiling solution of caustic potash and contain 10 to 15 per cent. of hygroscopic water, sometimes even more; they do not yield a coherent coke. Lignitic coals show much less tendency to disintegration, give less deep coloration to the potash solution, have less hygroscopic water, 5 to 9 per cent., and are practically non-caking. Coals are hard and firm, give only slight coloration to the solution of caustic potash and yield a non-coherent coke by slow coking, but a firm coke by fast coking. In the relations of carbon, hydrogen and oxygen they closely resemble some British non-coking coals. This grouping is very similar to that used by the United States Geological Survey, which is, lignite, subbituminous and bituminous coal.

Coal has been found in all portions of the Tertiary column. Pliocene deposits of some economic importance have been found in Italy, Hungary, Germany, New Zealand and Alaska. The Miocene coals of Hungary, Bohemia, Germany, Bosnia, France, Spitzbergen, Iceland and Greenland as well as those of Trinidad and the adjacent portion of South America are of great extent; coal of this age has been found in Central America and occasionally in North America, but the deposits are apparently unimportant. Oligocene coals are mined extensively in Hungary, Germany and Switzerland, but they have not been recognized definitively in North America ex-

[160] G. C. Hoffmann, "Chemical Contributions to the Geology of Canada," Rep. Prog. Geol. Surv. Canada, 1882–4, Pt. M, pp. 1, 2, 5–8; Ann. Rep. 1888–9, Pt. R, pp. 9–18.

cept in western Canada. Eocene coals are present in Bavaria, Austria and Hungary, but, for the most part, the areas are inconsiderable. Deposits of this age in India, Java, Sumatra and Borneo are well known, while those of western North America are the main source of supply for a vast area.

Classification of Tertiary Coals.—As the Tertiary brown coals have supplied a great part of the fuel consumed in Germany and much of France during more than two centuries, they have been classified to the last degree of detail. Brongniart[161] recognized four types, Lignite jayet, which he thought equivalent to Pechkohle, though it is evident that his reference is to the mineral jet; Lignite friable, la houille limoneuse of Brochant, regarded by him as synonymous with the German Moorkohle; Lignite fibreux, which retains the woody structure; Lignite terreux, bituminöse Holzerde, commonly known as Terre de Cologne, black to blackish brown, with fine-grained earthy fracture, mostly homogeneous, but containing embedded trunks of trees.

Zirkel's[162] grouping utilized the popular names as employed in Germany: Pechkohle, compact, brittle, pitch-black, waxy or greasy luster, conchoidal fracture; approaches stone coal but is structureless; Gemeine Braunkohle, or common brown coal, compact with more or less conchoidal fracture, less hard and brittle than Pechkohle, blackish brown to pitch black, with or without woody structure, passes on one side into Pechkohle and on the other into Moorkohle, a dense mass even in structure, black with bright streaks, is closely related to Erdkohle, or earthy brown coal, which is a friable mass of dust-like more or less loosely consolidated fragments, with dull luster and earthy fracture; Lignit or wood brown coal, in masses showing texture of wood, twigs, flowers, roots, etc.; Bastkohle and Nadelkohle are merely varieties of Lignit; Blätterkohle, Dysodil and Papierkohle are finely laminated; Wachskohle contains 62 per cent. of paraffin.

Zincken[163] presented a somewhat similar classification but in such detail as to exhibit sufficiently the great complexity of the group

[161] Al. Brongniart, "Mineralogie," T. 2, pp. 50 ff.

[162] F. Zirkel, "Lehrbuch der Petrographie," Bd. I., pp. 390–392.

[163] C. Zincken, "Die Physiographie der Braunkohle," pp. 168 ff.

known as brown coal. The terms, for the most part, are those in popular use, showing that the distinction between the several members is notable. (1) Gemeine Braunkohle, in more or less hard masses, with or without trace of woody structure, brown to blackish brown, with bright streak, dull fracture, breaks into irregular angular fragments, is intermediate between Erdkohle and Pechkohle; (2) Erdkohle, earthy brittle, yellowish to dark brown, wholly amorphous, much cleft by drying, alternating bright and dull laminæ, the former more common in the upper part of beds while the denser varieties in the lower part of the bed give a shorter flame. The varieties are very numerous; Schwelkohle, very bituminous, resinous, yields tar, illuminating gas and paraffin; Schmierkohle belongs in the upper part of beds and when damp feels like clay, Colnische umbra is an earthly brown coal utilized as coloring material, Russkohle, earthy, dusty, of irregular occurrence; (3) Lignit, masses of wood, more or less fossilized, passes over into ordinary brown coal, is yellow to dark brown and breaks like wood, may contain patches of Erd-, Pech- and Glanzkohle, some lignits in drying become Pechkohle. It is derived mostly from resinous trees, the stems being flattened by softening and pressure. The varieties are numerous; Bastkohle forming layers or parts of layers, more or less of bark structure belonging to *Pinus, Taxus, Alnus,* etc., Nadelkohle, bundles of tissues of palms with parenchyma removed; (4 and 5) Dysodil or Papierkohle and Blätterkohle, in very thin laminæ; (6) Moorkohle contains abundance of remains of swamp plants as well as compressed woody roots, small stems, etc., usually associated with deposits of lignit and occurs in the lower portion of the bed or fills spaces between the stems; (7) Pechkohle, dense, more or less brittle, rather tender, breaks into sharp angular fragments, black brown to pitch black, dull pitch-like to greasy luster and irregular to conchoidal fracture, passes over to common brown coal on one side or to Glanzkohle on the other; sometimes it occurs in Moorkohle, while at others it includes thin to 5-inch layers of Glanz-, derived from conifer stems pressed flat; (8) Glanzkohle is dense with conchoidal fracture, is blackish with greasy, vitreous or metallic luster; sometimes it forms whole beds but it is often as-

sociated with other types and not rarely one finds laminæ of Glanz- alternating with those of dull coal, giving a banded appearance to the section. This is the hardest variety of brown coal and is derived prevailingly from resinous woods. (9) Gayet or jet, dense, hard but not brittle, richly bituminous.

Von Gümbel[164] was satisfied with a much simpler classification. His subdivisions are Lignit, Pechkohle, typical Braunkohle, which includes all the other varieties of authors. He adds Faserkohle, the same with mineral charcoal or fusain.

Toula's[165] system is as simple as that of v. Gümbel, but quite different in the method of grouping. Glanz- and Pechkohle are varieties of the black coals; Moorkohle in many ways resembles peat; Blätterkohle or Dysodil and Lignit are defined by him as by other writers. All are allied closely to types of materials observed in peat deposits.

The array of terms is formidable, but the condition is less complex than it appears. A bed never consists wholly of any one type; ordinarily several kinds of coal are found in a single bed, where those most in contrast are often found in intimate association. The great variety shows sufficiently well that the term brown coal or lignite is applied to a group of substances differing in mode of occurrence as well as in chemical and physical character, among them some closely allied to peat and others which bear great resemblance to the Palæozoic coals. Owing to the great diversity in conditions, it is necessary to present descriptions of deposits in the order of their age and in some detail, reserving until the close an effort to determine the features which are in common.

The Pliocene Coals.—Descriptive notes respecting the Pliocene coals are comparatively few. Some of the deposits are on the border line between Tertiary and Quaternary, so that the age is indeterminate. Collier[166] discovered an area of this kind near the palisades of the Yukon River in Alaska. Bluffs of silt and gravel, 150 feet high, line the river and contain so many bones of large

[164] C. W. v. Gümbel, "Beiträge," etc., pp. 139 ff.

[165] F. Toula, "Die Steinkohlen," Wien, 1888, p. 18.

[166] A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 43, 44.

mammals that the deposit is known as the "bone yard." Recent land and freshwater shells as well as cones of a *Picea,* like those of the Yukon spruces are associated with them. These silts and gravels enclose beds of vegetable matter, one more than 20 feet thick, in varied stages of conversion, from pliable wood to brittle brown lignite. As a whole the similarity to recent peat is very close. Collier's description suggests that the deposits mark sites of flood-plain swamps, more or less forested and subject to overflows by floods which, like those of this day, left behind sands as well as the trees from undermined sandy banks of the river.

Haast[167] saw at several localities in New Zealand, deposits of lignite or "lignitic brown coal," belonging to late Tertiary or in some cases to early Quaternary. At one, the bed is 3 feet 2 inches thick and the coal retains the woody structure; at another, he measured 14 feet of brown coal while at a third, the section shows numerous beds, 2 inches to 5 feet thick, separated by fireclays, shales and porphyritic tufas. Some lignites are distinctly ancient peat bogs while others are composed chiefly of timber. Hutton[168] recognized undoubted Pliocene lignites at many places in southern New Zealand, especially around the margins of old lake basins and in river valleys, which existed prior to the great depression of the newer Pliocene. Occasionally, one finds well-preserved stems and usually the vegetable origin of the material is distinct to the unaided eye; but, at times, the mass is compact, brown, structureless and cannot be distinguished from brown coal. The thickness at one place is 30 feet; but "like all lignite beds" the deposits are local and not connected.

Hantken[169] states that in Hungary the Pliocene frequently contains lignite and that the deposits are freshwater, holding *Unio* and *Paludina.* The beds are broken by irregular partings and vary much, even abruptly, in thickness and quality. One bed has 8 benches of brown coal, in all 3.5 meters, with 7 partings of clay, the whole thickness being 6.36 meters. The lower benches are

[167] J. Haast, Rep. New Zealand Geol. Survey for 1873-4, pp. 14, 15.

[168] F. W. Hutton, "Geology of Otago," Dunedin, 1875, pp. 96, 98.

[169] M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Kröne," Budapest, 1878, pp. 341, 343, 352, 353.

harder than the upper ones. At another place, the bed consists of brown coal, 7.5 meters, clay, 0.25 meter, brown coal, 0.25 meter. The lower bench is harder and better than the upper one, which is crowded with stems of *Sequoia langsdorffii*. The roof is clay, with impressions of plants.

Von Ammon[170] has described the Gustav mine, near Oettingen a.M. in Bavaria, as yielding Moor- and Mooskohle with included Lignit (bituminöse Holz). This chief bed, underlying upper Pliocene clay, is from 8 to 16 meters thick and is mined in open workings within an area of about 2,000 acres (800 ha). At Schwarzenfeld, the workable coal is but 2.5 meters thick and contains not far from 16 per cent. of wood. In all cases, the observer appears to have been impressed profoundly by the resemblance of these deposits to peat beds, both in structure and in distribution.

Miocene Coals.—Marine conditions prevailed in the present coastal plain along the Atlantic in North America during the Miocene and conditions favoring accumulation of vegetable matter did not exist in the adjacent region, for no coal has been found. But the vegetation was there and swamps were on some of the streams. Berry[171] discovered the remains of a cypress swamp near Richmond, Virginia, associated with the well-known diatomaceous earth of that region. Among the characteristic plants are *Taxodium, Nyssa, Salix, Quercus* and others of types familiar in modern cypress swamps. The conditions for some reason were equally unfavorable elsewhere on the continent, and no coal positively identified as Miocene has been found anywhere in economic quantity except within a petty area in California. There,[172] in the Monte Diablo range, is the bed, which was mined long ago and for many years was the chief source of fuel for steamboats. The bed, as measured by Arnold, is 14 to 16 feet thick and has a dip of about 70 degrees. The coal varies greatly in quality both vertically and horizontally, specimens from some openings being, in composition, very much

[170] L. v. Ammon, "Bayerische Braunkohle," etc., pp. 15–21, 26, 27.

[171] E. W. Berry, "A Miocene Cypress Swamp," *Torreya*, Vol. VIII., 1909, pp. 233–235.

[172] R. Arnold, "Coal in the Monte Diablo Range," U. S. Geol. Survey, Bull. 285, 1906, pp. 223, 224.

like bituminous coal while those from others are lignitic. There is a marked variability in the percentage of ash. In burning, this coal gives off an enormous volume of smoke.

Pardee[173] has recorded brief notes respecting deposits in Montana, which appear to be on the border line between Miocene and Oligocene. They are lenticular and consist of remains of vegetation, which grew on the flats, mingled with silts from the muddy water which frequently flooded the spaces. The coal attains a maximum thickness of 7 feet, is banded, with alternating bright and dull laminæ, has semi-conchoidal fracture, splits along the bedding planes and has two sets of joints, intersecting at right angles. It is usually dense and brittle, but at one mine some of the layers are rather tough and woody. The streak is brownish and the coal tends to slake on exposure. The dip throughout the region is gentle.

The Miocene coal of Greenland was discovered long ago and it has been utilized in a small way. Brown[174] gave numerous sections from one area. The important bed of the region explored by him is on Heer's creek, where it is double, showing coal, 2 feet 6 inches, shale, 1 foot 6 inches, coal, 1 foot. The coal is but slightly coherent, has cubical fracture and breaks down readily on exposure. Retinite is abundant in lumps from mere specks to the size of a marble. Many stems of trees are in the upper bench, but they have been replaced with chert. Somewhat later, Heer[175] described a bed of coal near Discovery Harbor, 25 to 30 feet thick and with extreme dip of 10 degrees. The overlying black shale is rich in plant remains; among which, as in Spitzbergen, conifers hold the first place, ten species having been recognized; with them are eight species of dicotyledons, belonging to families usually well represented in swamp floras, such as birch, elm, waterlilly and other types of similar habit. Heer regards the whole assemblage as indicative of swamp origin for the deposit. The coal falls to pieces readily on exposure;

[173] J. T. Pardee, "Coal in Tertiary Lake Basins of Southwestern Montana," U. S. Geol. Survey, Bull. 531 G, pp. 11–15.

[174] R. Brown, "Geological Notes on the Noorsack Peninsula," etc., *Trans. Geol. Soc. Glasgow*, Vol. V., 1877, pp. 91, 95.

[175] O. Heer, "Notes on Fossil Plants Discovered in Grinnell Land," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 68–72.

but the analysis of an air-dried specimen by R. J. Moss as given on p. 563 of the volume just cited, shows for it a composition not far from that of a well-advanced bituminous coal: Water, 2.01; ash, 8.49; carbon, 82.97; hydrogen, 6.15; oxygen and nitrogen, 10.87.

The coal beds of Trinidad,[176] in the West Indies, are part of a deposit originally continuous southward in Venezuela, where it underlies an area of not less than 36,000 square miles. This region lies south from N. L. 10 degrees, where the climate during the Miocene was intensely tropical, as it still is. The newer Parian group has a fauna allied to that of the Miocene and the coal beds are in the lower members, the Caroni and the Moruga. Those of the former, from mere films to 4 feet 6 inches thick, are well shown in the interior where the upper beds, with dip of 15 degrees, are distinctly ligneous, but the lower beds, with dip of 40 to 50 degrees, are, to the naked eye, structureless. No roots were recognized in the underclays. The Moruga beds are not important; frequently they are little better than carbonaceous shale. At two places, roots were seen "rectangular to the bases of the strata." The accompanying rocks in both divisions are chiefly shales, but the Caroni contains a thick sandstone with ripple-marked surfaces.

Returning to the north, important deposits of coal[177] have been opened in the Miocene on Advent Bay. The bed is triple at 60 yards from the crop, showing coal, 1 foot 8 inches, clay, 2 to 4 inches, coal, 1 foot 7 inches, sand, 3 to 5 inches, coal, 1 foot.

In the upper benches the coal is hard, grayish-black, imperfectly laminated and with a somewhat conchoidal fracture. The bottom bench is black, laminated, rather lustrous and tends to be prismatic. Mineral charcoal is present in considerable quantity. In general appearance, coal from the upper benches is mostly splint-like but that from the lowest bench is remarkably like ordinary bituminous coal. Air-dried specimens contain less than 5 per cent. of water. Caustic potash solution attacks the coal throughout and acquires a very in-

[176] G. P. Wall and J. G. Sawkins, "Report on the Geology of Trinidad," London, 1860, pp. 41–50.

[177] J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XII., 1895, pp. 82–95. The assignment of this coal to the Jurassic is an error; Nathorst has shown that it is Miocene.

tense coloration. On the pure coal basis, the upper benches contain almost 10 per cent. more volatile than that from the lowest bench.

The Sutarbrandur of Iceland was described briefly by Jardin.[178] Robert had supposed that these deposits consisted merely of driftwood, but Jardin recognized that the quantity is too great to admit of that explanation. The beds are numerous, having been seen on all coasts except the southern; they are horizontal and their thickness is from mere films to 12 meters. The material is sometimes compact and free from inorganic admixture, at others, it is fragmentary, mingled with pebbles and dirt while at others still it is almost pulverulent. When compact it consists of alternating dull and bright laminæ. Mouchet's study with the microscope showed that this coal is derived chiefly from conifers.

Geikie[179] states that in the Faeröe Islands coal of Miocene age is associated with dark carbonaceous clays and is more or less lenticular. The formation is 10 to 15 feet thick on the island of Suderöe, where he observed two types of coal; one is bright, with glassy fracture, not soiling the fingers and not unlike some of the Scotch parrot coals; the other is dull, lusterless, soils the fingers and shows vegetable structure. These alternate in the seams but the dull slaty coal is more abundant than the other. Johnstrup, cited by Geikie, held that every lens of glance represents a flattened stem, in which annual rings can be seen. Geikie found this not true of the thinner streaks and threads. The glance coal has 12 to 14 per cent. of water and only 2.5 per cent. of ash; whereas the better quality of the slaty coal has 11 to 17 per cent. of water and 10 per cent. of ash. The conditions resemble those in the Scottish coal fields, which led Geikie to suggest that the coals are due to gradual accumulation of different plants or of different parts of the same plants.

Fournet[180] saw at Sonnaz near Bourget in France a coal bed with this structure: Lignite, 1.30 m.; clay, 0.30 m.; lignite, 0.10 m.; clay, 0.05 m.; lignite with *Planorbis,* 4 m.

[178] E. Jardin, "Note sur le Sutarbrandur d'Islande," *Bull. Soc. Geol. France,* II., Vol. 23, 1866, pp. 456–459.

[179] J. Geikie, "On the Geology of the Faeröe Islands," *Trans. Roy. Soc. Edinb.,* Vol. XXX., 1882, pp. 227–230, 240, 267.

[180] J. Fournet, "Note sur les lignites tertiaires de la Tour-du-Pin (Isère)," *Bull. Soc. Geol. France,* II., Vol. XI., 1854, pp. 763–772.

This bed underlies 52 meters of sand and gravel; at 5 meters below it is a thin streak of lignite resting on white clay, which contains *Helix* and *Planorbis*. At Tour-du-Pin, the partings are marly and the underclay contains laminæ of lignite, which become thicker as the bed is approached. The lignite there is distinctly laminated and is so hard that it can be removed only with picks. The laminæ, completely "bitumenized," show vegetable impressions but no leaves or flattened stems. Near Vion, on the border of Isère, mineral charcoal is abundant between the laminæ and embedded trunks of trees are not rare. Some parts of this deposit are brown, but others are "bitumenized." The constituents are distinct, for Fournet recognized débris of birch, juniper, fir, cherry and walnut, with sedges, rushes, elytra of insects and *Planorbis*. He was impressed by the remarkable resemblance to coal beds; the partings, the passage of the floor into the lignite, the lamination and the abundance of mineral charcoal. One cannot fail to see in Fournet's description an equally close resemblance to peat deposits; land and freshwater mollusks, elytra of insects, all found in the lignite as well as in the underclay, the character of the plants, the structureless mass in which the plant remains and the shells are embedded.

Daubrée[181] published some notes respecting his observation in the Lower Rhine area. Near Soultz-sous-Forets, he found marls with layers of sand. The latter contain bituminous lenses, which near Bechelbronn have 2 per cent. of bitumen with some pyrite. They hold much carburetted hydrogen and disastrous explosions have occurred in the works. Some thin beds of lignite were seen, which have impressions of *Helix, Lymnæa* and *Bulimus*. The same shells were seen at Lobsann, where, above the marls, are freshwater limestones with thin lignites, in all from 5 to 9 meters thick. This limestone yields 10 to 18 per cent. of bitumen and contains gypsum as well as pyrite. It is rich in *Chara,* the individuals being silicified and remarkably well preserved; but other remains of vegetables are in poor condition.

The lignite streaks are very thin and only some millimeters apart, there being alternate layers of lignite and limestone, sometimes 40

[181] Daubrée, "Notes sur le gisement du bitume, du lignite et du sel," etc., *Bull. Soc. Geol. France,* II., Vol. VII., 1850, pp. 444–450.

to the meter; but occasionally the lignite is 30 to 60 centimeters thick and is mined. Quartz masses are present in the lignite as well as in the limestone, which, judging from Daubrée's description, are probably of secondary origin. This Lobsann fuel is the lignite bacillaire, the Nadelkohle, which is merely débris of palm trees, from which connective tissue has been removed, leaving the loosened bundles of fibers. This constitutes the greater part of the beds and the arrangement shows that the stems were prostrate. But with this is another fibrous type, much finer and allied to mineral charcoal. Microscopic examination proved that this is derived from coniferous wood; palms and conifers were associated in the forests. Succinite is abundant in this lignite, but the balls are rarely larger than a pea and usually are of pinhead size; he counted 40 droplets in a cubic decimeter. It is most common in beds consisting largely of coniferous débris, the fibers of mineral charcoal being still impregnated with the resin, as appears distinctly under the microscope. This lignite is always laminated, the laminæ being less than one millimeter thick and alternately bright and dull, the latter being the less pure. *Bulimus* and *Planorbis* were obtained from the lignite. This freshwater series of lignites and limestones is succeeded by marine marls, containing *Spatangus, Cerithium, Venericardia* and other forms of similar habit.

Potonié[182] described the great deposit of brown coal near Senftenberg in Niederlausitz. The bed is more than 10 meters thick, and is mined by stripping at several places. The author gives reproductions of two photographs, one being a panorama of the principal excavation, the other showing distribution of erect stumps. As in many recent and Quaternary peat deposits, one finds here several generations of forest, one above the other, embedded in humus material, the only difference being that homogeneous peat has been converted into brown coal. In the floor, as in the roof, are many great erect stumps, those of the former being rooted in the underclay, those of the latter, in the brown coal. Some stumps have a diameter of several meters and the intervals between trees are such

[182] H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes," *Jahrb. d. k. preuss. geol. Landesanst. f. 1895*, p. 97 ff. Citations from separate, pp. 19–24.

as are observed in recent forests. These belong mostly to *Taxodium distichum,* the bald cypress of American swamps. Many of the stems are hollow and, especially those near the bottom of the mass, contain Schwelkohle. The presence of an ancient Torfmoor, resting on the clay cover of the brown coal, indicates that peat-making conditions recurred here until diluvial accumulations began. The sand overlying this old bog contains erect stems belonging to either *Pinus sylvestris* or *Picea excelsis* and stumps have been found in the peat itself. One great uncompressed fragment of a trunk was found by Potonié, but usually the prostrate stems are flattened. The presence of Schwelkohle in the hollow stumps led the author to suggest that it was formed by the flow of resins, which, he thinks, must have been great in the injured trees. Schwelkohle is, for him, essentially a fossil resin; it burns with brilliant flame when pure.

The forest of the roof is well shown in a photograph reproduced on a postal card, for which the writer is indebted to W. Gothan of Berlin. It shows ten or more erect stumps, 4 and more feet high, distinctly rooted in the coal and associated with some prostrate stems. These were overwhelmed by the detritus which brought peat-growth to an end. Kukuk[182a] has reproduced a noteworthy photograph of the Victoria stripping in Niederlausitz. The brown coal has been removed and the floor is exposed with the very numerous great rooted stumps of *Taxodium distichum.*

Russwurm[183] has given a section of the brown coal bed at Orebkau, about 50 miles south-southwest from Frankfurt a.O. and somewhat more than 10 miles northeast from Senftenberg. The bed is 9 meters thick, is divided by a thin parting and underlies 10 meters of mostly black clay, containing comminuted fragments of plants. The upper bench, free from wood, is lump coal (Knorpelkohle) and bears shipping, so that briquetting is unnecessary; but the lower bench is fine coal (Formkohle) and tender, but it is rich in wood, the quantity increasing downward until at the bottom the stems predominate. Russwurm found no erect stems. A second bed, at times 3 meters thick, is here at half a meter to 4 meters below the main

[182a] P. Kukuk, "Unsere Kohlen," Leipzig, 1913, p. 25.

[183] P. Russwurm, "Braunkohlen Formation, etc., bei Orebkau," *Zeitsch. f. pr. Geol.,* Jahrg. 17, 1909, pp. 87 ff.

bed; at one excavation, the beds are so near together that they are mined as one, but elsewhere they must be mined separately.

According to Katzer, the Bohemian brown coals belong to the Miocene. Grand'Eury[184] says that at Steinkirche near Budweis in southern Bohemia, the mass of lignite, at the bottom of a superficial basin, filled with sand, lignitic clay, wood, herbaceous plants and roots, is a forest peat covered with mud. Katzer[185] reports that in the Budweis area he saw a coal bed, consisting of an upper bench, 3 decimeters thick, with stems almost completely coaled, and a lower bench consisting mostly of Moor- and Erdkohle. At another place, a bed, 2 meters thick, holds here and there, a great abundance of stems and is so pyritous that it is utilized in the manufacture of vitriol. The same author[186] has described the Grottauer beds on the Neisse River, immediately south from the border of Saxony, which are in the middle or lower Miocene. In one shaft, 45 meters deep, 47 layers of alternating coal and shale were crossed. The important bed, reached at 4 meters from the surface, has four benches of coal, in all 10.35 meters, separated by three thin partings of clay and shale. Another shaft shows similar alternations but the succession differs somewhat, the second and third partings being irregular, sometimes absent. The principal bed has an extreme thickness locally of 16 meters in the western part of the trough, where dips rarely exceed 5 degrees and the beds show little evidence of disturbance, aside from crevices in the coal. The eastern wing of the trough is much disturbed, faults and folds occur frequently while the crevices in the coal, often still open and half a meter wide, extend downward 5 or 6 meters. Sulphates, chiefly alum, are shown on the walls of these crevices.

The Grottauer brown coal consists very largely of "fossilized wood." Freshly removed from the mine, it has a wood-earthy appearance; but when dried the blocks not only preserve the wood structure but show also the forms of stems, roots and branches, all

[184] C. Grand'Eury, "Sur la formation des couches de Stipite," etc., *Comptes Rendus*, T. 130, 1900, p. 1688.

[185] F. Katzer, "Geologie von Böhmen," Prag, 2te Aufl., 1892, p. 1425.

[186] F. Katzer, *Oesterr. Zeitsch. f. Berg. und Hütt.*, Bd. XLV., 1897. Separate, pp. 5–18.

pressed flat. The color is brown or reddish brown, but usually the bark is black. Stems and coals are not in separate layers but are intermingled. At times the coal is very impure and spaces between the stems are filled with loamy mud. Occasionally one finds nests of soft, deep black, sometimes granular coal, resembling linden charcoal. The fresh material can be worked with a knife, saw or plane; after complete drying, it can be pulverized only with difficulty. The wood-like coal, dried at 110° C., has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.27. This is better than the average as generally the ash is higher.

The "gas coal" of Falkenau occurs, according to Katzer, as the top bench of the middle coal bed at that place, and is somewhat more than 30 inches thick. The lower benches of the bed are thin, irregular and of poor quality. Von Gümbel's[187] study of this Falkenau material showed that it consists chiefly of much disintegrated vegetable matter. Treated with Bleichflussigkeit, it exhibits the needles of intermingled Faserkohle. With these are abundant pollen exines and very many minute bodies resembling those seen in diluvial brown coals. The deep brown spores of lichens or algæ are clearly recognizable. The voluminous mostly white ash, 7.75 per cent., consists of clay flakes and quartz grains with some fragments retaining plant texture. This composition, as ascertained by v. Gümbel, is very much like that of a Lebertorf.

The Lower Miocene deposits of Brennberg near Oedenburg in Hungary were studied by Nendtvich,[188] who described the coal as a lens. It has suffered much from disturbance, the dips varying from 40 to 50 degrees and crevices in the coal are filled with Russkohle (soot-coal) and slate. The thickness in the deeper part of the basin is from 10 to 20 fathoms, but the bed decreases toward the borders. The woody structure is distinct in some portions of the coal, which are finely fibrous and in part like ebony. The faux-toit is well-marked, consisting of alternating layers of coal and clay, and shows leaf impressions. According to Grand'Eury, the underclay contains no roots.

[187] C. W. v. Gümbel, "Beiträge," etc., p. 145.

[188] C. M. Nendtvich, "Ungarns Steinkohlen," etc., *Haidinger's Berichte*, Bd. III., 1848, p. 38.

Hantken[189] summarized the available information respecting the Miocene coals of Hungary. He found that the conditions in the middle Miocene resemble those in the Pliocene, in that the coal deposits occupy very small areas and vary greatly in thickness as well as in quality. A bed near Edeleny, 3.24 meters thick, has four benches; the clay partings are in all less than three fourths of a meter; one is pyritous, another contains *Helix* and plant remains and the third is carbonaceous. The underclay is carbonaceous and contains *Helix* as well as plant impressions. The deposits near Brennberg and Saljo-Tarjan are more important. The coal bearing group, at the bottom of the Miocene, is 27 to 40 meters thick and holds four coal beds at Brennberg, from 2 to 7.5 meters extreme thickness. The overlying sandstones are about 130 meters thick. At Saljo-Tarjan, the main bed is 2 meters thick, underlies sandstone and conglomerate and rests on marly clay. But Grand'Eury found that the floor varies. At an opening in Saljo-Tarjan, the coal rests on rhyolite-tuff, but at Mitra-Novak one coal bed rests on sandstone while another rests on clay.

Katzer[190] has described in considerable detail the brown coal deposit near Banjaluka in Bosnia, which, according to the fauna, appears to be Miocene, though its flora indicates Oligocene age. Tertiary beds occupy a basin of about 80 square kilometers and are surrounded by rocks belonging to different periods. The succession of psammites, marls, limestones and tender conglomerates is apparently freshwater throughout. The one important coal bed, mined near Banjaluka, is in three benches; the partings are very thin in the northwest part of the mine, where the bed is single; but they thicken rapidly, the upper and middle benches disappear in succession and only the lowest or Laũser bed remains. Where the bed is triple as in the Laũser district, the succession is: Hard limestones and soft marls, freshwater, 100 meters; marls, more or less carbonaceous, containing *Melanopsis;* upper bench of coal, with extreme thickness of 4 meters; gray to brown marls, calcareous, containing on top layers of compressed *Unio;* middle bench of coal, 2 meters; yellow to gray soft

[189] M. Hantken, "Die Kohlenflötze und Kohlenbergbau," etc., pp. 313–325.

[190] F. Katzer, "Die Braunkohlen Ablagerung von Banjaluka in Bosnien," *Berg. u. Hütt. Jahrb.*, Bd. LXI., 1913, pp. 153–227.

marls, with many films of bright coal and layers filled with compressed fossils, mostly *Planorbis* and *Melania;* Laüser coal or bottom bench, 2 to 2.5 meters; gray, brown to blackish sandy marls with thin-bedded calcareous marls holding coal smuts and carbonaceous shale.

In reading this section, one might easily suppose that it refers to some peat locality in northern Ohio. The coal differs somewhat in the several benches but the general character is the same throughout. The woody portions pass gradually into Pechkohle, which is the prevailing type and is not always laminated.

The Oligocene Coals.—In the Zsil Valley of Hungary, according to Hantken,[191] the great adit, which crosses 567 meters of Oligocene rock, dipping at 30 degrees, cuts 14 beds of coal, one of which is 41.12 meters thick. The marly beds in contact with the coal are very dark and contain carbonate of iron. At Szt. Ivan in the Gran district, a bed, 12.4 meters thick, has four benches of coal, the partings being freshwater limestone and in all 3.7 meters thick. It underlies a conglomerate of dolomitic fragments and rests on a carbonaceous shale passing downward into freshwater limestone. Partings in coal beds of this Gran area show notable variations in thickness, one of them increasing in a short distance from 1.9 to 17.45 meters. Freshwater conditions seem to have prevailed almost throughout, but in the Nagy-Kovacsier basin, the lowest coal bed underlies shale containing *Natica* and *Cerithium,* though freshwater limestones are the predominating rocks above. The coal shows marked variation in composition. Nendtvich[192] said in 1848 that the coal of the Gran region is black, with dull luster, mostly shaly but sometimes with conchoidal fracture. It is non-caking and yields only a slightly luminous gas. The woody character must be marked, for Nendtvich speaks of the material as tough and hard to pulverize. The chief drawbacks are the readiness with which it falls to pieces on exposure and the tendency to spontaneous combustion.

The Oligocene coals of Germany are found in many small areas. Plettner[193] described in detail the greater number of the compara-

[191] M. Hantken, "Die Kohlenflötze," etc., pp. 247, 259, 260–263, 280, 286, 289.

[192] C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 25–31.

[193] Plettner, "Die Braunkohlen Formation in der Mark Brandenburg," *Zeitsch. d. d. geol. Gesell.,* Bd. IV., 1852, pp. 249–483.

tively small basins within Brandenburg, where the coals are of great importance. At Wittenberg, on the Elbe, where the bed is 8 to 12 feet thick, the coal is blackish-brown and pulverulent; the inhabitants wet it and mould it into bricks. The upper part of the bed contains much fine quartz sand, but there is none in the lower portion. The dips vary from 9 to 20 degrees. A rather extensive basin is near Muskau, on the Neisse River about 70 miles south of east from Wittenberg, where the coal is hard, imperfectly laminated and shows numerous imprints of leaves on surfaces of the laminæ. It rests on a fine clay and underlies about 10 feet of sand, succeeded by 5 inches of leaf-bearing clay, above which is another coal bed of unknown thickness. The coal is dull with earthy fracture and shows no trace of organic structure, aside from the leaf imprints. A yellow resin, mealy or dust-like, is abundant. At Grüneberg, 50 miles northeast from Muskau, the coal is hard and laminated; it is dark brown but the included plant remains, heaped in great quantity on the surfaces of laminæ, are yellowish brown. The waxy yellow resin is plentiful and is often enclosed in the fossil wood, especially between the annual rings.

Fürstenwalde is near the river Spree at a few miles west from Frankfurt a. O. Plettner has preserved the records of numerous shafts and borings, which exhibit such variations that the coal beds must be lenses. The dips are from 20 to 70 degrees. The important bed is triple. The great bench at the bottom, 10 to 11 feet thick, is the best and usually contains little Formkohle; but, at times, that type of coal forms most of the upper benches. There is a notable difference in quality, coal from the middle bench being the worst. Plettner in this district distinguished three types of coal, which he recognized elsewhere: (1) Knorpelkohle, the hardest and most appreciated, brownish to coal-black, with at times a bluish luster; it breaks into Knorpel or sharp-angled parallelopipedons, 2 to 9 inches in diameter; the fracture is earthy, luster none and plant remains are not common; (2) Erdig- or Formkohle, light brown, of loose texture, earthy, friable. (3) Bitumenöse Holz, which is present in all benches of a bed, embedded in the coal; sometimes it is fragmentary but at others whole stems are found; these are usually prostrate, erect stems being

rare. There is little difference in the wood and the fragments appear in all cases to belong to the genus *Pinus*. Ordinarily they are compressed and the annual rings are ellipsoidal. A yellowish-white resin, without succinic acid, is present in all types of the coal.

Buchow, west from Fürstenwalde, is at a few miles east from Berlin. There the coal is laminated with, as Plettner remarks, enough bitumenöse Holz to keep one from forgetting the vegetable origin of the coal, as he might do if he consider only the homogeneous substance in which the wood is embedded. At Freinwalde, 15 or 20 miles north-northeast from Berlin, the dip is only 10 degrees, whereas at Buchow it is 15 to 60. The coal at Freinwalde contains no wood and burns with a very disagreeable peat-like odor; this type, observed also at Buchow, is the Moorkohle of Plettner. Plant remains, recognizable by the unaided eye, are few, and such as were seen were pierced by threads of resin; but, in the neighboring area of Falkenburg, wood abounds.

This Moorkohle is shown near Frankfurt a. O. and at some other places. The dips in the basins of this eastern region vary from 10 to 60 and in one basin even to 90 degrees. At most localities the coal is laminated and contains resin as well as wood; the latter is often converted into Pechkohle and in that conversion it loses structure. Plettner calls attention t othe fact that the change into Pechkohle rarely affects the whole fragment. The converted portion is not altered by exposure to the air and does not separate into lamellæ.

The coals of Sachsen or Prussian Saxony have been studied by many observers. Laspeyres[194] examined an area near Trotha and Dolau, where the coal was mined by stripping. The lower bed is 2 to 6 meters thick and divided by an irregular parting of sandy clay. The upper bench is often so poor as to be worthless; the lower bench is better but consists chiefly of Formkohle with some Knorpelkohle. It contains much coarse or earthy retinite in nests, streaks or layers, as well as much pyrite, petrified wood and charcoal. At a little distance higher is the upper bed, with extreme thickness of 5 meters. This consists of Formkohle, small particles of brown-black coal, more or less closely packed together. Occasionally it is dust-

[194] H. Laspeyres, "Geognostische Mittheilungen aus der Provinz Sachsen," *Zeitsch. d. d. geol. Gesell.*, Bd. XXXIV., 1872, pp. 298–302.

like and of cinnamon color, a Schwelkohle. Some Knorpelkohle is present along with bituminöse and petrified wood, the replacement in the latter being with pyrite or silica. The plant remains are chiefly wood, which predominates in some parts. This is wholly coniferous and, excepting a few Abietinae, belongs to cypress. Occasionally one finds great stems passing gradually into either earthy or compact coal, in which Laspeyres thinks he has proof that the varied conditions observed in coal must be ascribed to irregular working of the conversion process, though he is convinced that much of the earthy brown coal may be due to destruction of other parts of the plants, which, being tender, offered less resistance to the process and lost all structure.

Credner,[195] in discussing the same area, gives as the Oligocene succession: Lower, consisting of light-colored sands, clays with brown coals; Middle, dark gray to green gray sands and clays with marine forms; Upper, light-colored sands, gravels, clays with brown coals.

The Lower Oligocene, about 100 meters thick, is a mass of irregular variable strata. The coal beds are usually 4 to 5 meters thick but in places a maximum of 8 or 9 meters is reached. There seem to be practically two beds, but his general statement exhibits the irregularity of deposit, for he says, (1) That the beds are not continuous, but are interrupted locally, as they thin out; (2) Consequently only one bed occurs in places where two were expected; (3) It is questionable if these apparently local, lens-like individual beds are actually one and the same throughout, for the relations of the beds are extremely variable; (4) Locally, one finds more than two beds.

The coal is mostly earthy or soft brown coal, mingled with more or less of Knorpelkohle and bitumenöse Holz, the latter sometimes though not often replaced with pyrite and silica. The woody material is in small proportion and all the phenomena indicate swamp origin. In this connection he cites A. Penck's investigation of the Tanndorf brown coal, which showed that the lower shaly portion of the deposit is rich in well-preserved remains of floating plants,

[195] H. Credner, "Das Oligocän des Leipziger Kreises," *Zeitsch. d. d. geol. Gesell.*, Bd. XXX., 1878, pp. 615.

such as *Salvinia* and *Trapa;* the next layer is full of *Arundo* stems with leaves of *Salix,* evidently blown by the wind. Above this is the coal, composed of *Sequoia, Betula* and *Palmacites* stems. One sees here the gradual filling of a freshwater basin, through accumulation of *in situ* vegetation. The abundance of still erect tree stems, some rooted in the floor and others rooted in the coal itself and extending meters into the overlying sand, suggest that all the stems, prostrate as well as erect, are those of an *in situ* vegetation.

Naumann[196] remarks that stems, prostrate, piled irregularly and compressed, are often enclosed in earthy brown coal. At times, however, erect trees are found, cylindrical and retaining their roots, so that they are where they grew. One finds in these areas that locally all the prostrate stems lie in the same direction, showing that the same force had broken them off and laid them down. He adds a new example of erect trees. Some years prior to publication of his work, the brown coal had been exposed by stripping near Würzen in the province of Sachsen; on the surface of the coal, within a space of about half an acre, he saw between 40 and 50 trees, their roots interlocked within the coal bed.

A mineral, termed pyropissite, occurs at numerous places within Sachsen, sometimes pure but often mingled with ordinary brown coal to form the Schwelkohle, which has been of no little importance as a source of oils. Stohr's[197] description of conditions, prefacing his discussion of pyropissite, gives some details not recorded by the authors already cited. The strata generally are in no regular order and appear to dovetail; the brown coal alone appears to be well-defined. The formation is from 30 to 60 meters thick and underlies 3 to 30 meters of diluvial deposits. The roof of the coal is sand, clay or hard sandstone and there is a similar variation in the floor, though commonly that is plastic clay. The brown coal, where mined, averages about 6 meters, but the thickness varies from a few centimeters to 10, 16 and at one place 20 meters. Owing to irregularity in the floor, due to prior erosion, the coal occurs in shallow

[196] C. T. Naumann. "Lehrbuch der Geognosie," 2te Aufl., 1862, Bd. III., p. 204.

[197] E. Stohr. "Das Pyropissit Vorkommen in den Braunkohle bei Weissenfels und Zeitz." *Neues Jahrbuch*, Jahrg. 1867, pp. 407–409.

troughs but sometimes it crosses the separating ridge. Not unfrequently, there are "Sandsäcke," where the roof descends, at times, even to the floor. Usually these are filled with sand or gravel but sometimes with plastic clay. The coal is really in one bed, divided in some places by a sandy parting. The lower portion is Knorpelkohle, but is inferior as it contains much pyrite. The upper bench, though Formkohle, is a good fuel. Occasionally, a worthless, heavy, sand-like dust, termed Russkohle, composes whole layers in the bed. Pyrite, gypsum and retinite accompany the coal; at one place, amber, in lumps as large as one's fist, is found in the roof. Bituminous wood, pressed flat, as well as silicified wood is found in many mines.

Fiebelkorn[198] at a later date described the area examined by Stohr. Like him, he recognized only one bed, which where mined is from 4 to 21 meters thick and occupies a rather regular trough. Occasionally another bed, about one meter thick, is seen above it, the interval being filled with clay. The main portion of the trough is divided into numerous subordinate troughs separated by low ridges. Very often the coal is wanting on these ridges and the coal in the troughs is lens-like. The coal is usually earthy in type, a more or less friable mass of yellowish or reddish to dark brown or black material, coarse-grained, with rather shining streak and in general showing no organic texture. Toward the bottom, it not rarely becomes Knorpelkohle; but for the most part it is Formkohle and on drying falls into dust. The bed contains numerous coaled stems separated by spaces of one to five meters. The overlying beds are a succession of white and dark sands with some clay layers, all well exposed at several places where the cover is stripped. The floor is usually clay but sometimes sand. It is well shown near Teuchern and near Granschutz, where roots decending into it from the coal are distinct. He traced these in some cases to the depth of a half meter. They are those of reeds, grasses and rushes, marking the floor of a swamp.

Potonié regarded the Formkohle as, in most cases, of secondary-allochthonous origin. It was originally an autochthonous coal but had been removed and redeposited elsewhere. To this matter, refer-

[198] M. Fiebelkorn, "Die Braunkohlenablagerungen zwischen Weissenfels und Zeitz," *Zeitsch. f. pr. Geologie,* Jahrg. 1895, pp. 353–364, 396–415.

ence will be made in another connection. Raefler,[199] opposing the doctrine, examined closely most of the mines in the Sachsen area. Extended reference to this work will be made in discussion of the doctrine of Potonié. The plates illustrate well the lens-like form of the brown coals, showing isolation of the several portions of the beds and suggesting that the lenses were not wholly contemporaneous. The rudely crescent forms observed in cross-sections of the lenses with depressed upper surface make clear the effect of compression on the thick mass of vegetable matter midway in the little trough. Several of his profiles indicate "Sandsäcke" filled with "glazial Diluvium." The coal is very little disturbed in many places but in others the plications are very close. Some of these are evidently preglacial and the erosion was extreme; but it does not seem to have been contemporaneous in any case.

Pyropissite occurs in some portions of the Sachsen area. It is described by Zincken as amorphous, earthy, with earthy fracture; it is gray to yellowish to white, greasy to gummy feel and fuses to an asphaltic mass; it passes into Schwelkohle, a mixture of pyropissite and ordinary brown coal. Here only the geological relations may be considered; other matters belong under chemistry as of the brown coals.

Stohr,[200] in the memoir already cited, states that in southern Sachsen pyropissite is an integral part of the coal bed. The pure mineral yields 40 to 50 pounds of tar to the ton, from which paraffin and mineral oil are obtained; the ordinary material yields only 20 to 25 pounds. Until recently, the Schwelkohle was thought to be worthless and of rare occurrence; but, though absent from most of the area, it is present at many localities. It is not always a distinct bench, but at times forms laminæ in the upper part of the Feuer- or fuel coal. The distribution seems to be lens-like, for Stohr refers to nests of Schwelkohle. A variable layer of Russkohle intervenes between the Schwelkohle and the roof, ordinarily not more than 6 inches thick, but at one stripping he found this layer from 2 to 3 feet. He summarized his observations thus:

199 F. Raefler, "Die Entstehung der Braunkohlen lager zwischen Altenburg und Weissenfels," Inauguration Dissertation, Jena, 1911.

200 E. Stohr, *Neues Jahrbuch*, 1867, pp. 410–424.

Pyropissite occurs only where the cover is less than 16 meters; (2) it is sometimes the upper bench, but, where the bed is very thin, it is the only bench; it is not always limited to the upper bench but it may be distributed in the underlying Feuerkohle; it occurs as leaves in the main Feuerkohle, sometimes with distinct demarcation from the surrounding coal but at others passing gradually into it; (3) it is always accompanied by Russkohle, gypsum, and pyrite; retinite appears to be absent; (4) the character of the roof may be important; under gravel and sand it is better than under clayey conglomerate; but under a clay roof he has seen it both good and bad.

Von Gümbel[201] studied the pyropissite of Weissenfels. It is powdery, dust-like, brown-yellow and difficult to moisten. Under the microscope, it shows only indefinite grains, opaque lumps and scattered leaves, ill-preserved and belonging apparently to some moss. After removing the resinous substances by alcohol and ether and treating the residue with Schultze's reagent, he found little evidence of organic texture, aside from something like Faserkohle; there are some spiral threads, and spores and pollen are indicated by rounded patches. The ash, 14.2 per cent., consists of quartz grains, crystals and opaque black balls. No diatoms were seen. Pyropissite from Sauforst in southern Bavaria and of Miocene age, is in general much the same; but remains of grasses and of moss leaves are numerous, while pieces of wood are present, retaining structure though converted into a yellow friable material like the groundmass. After treatment with ether, the parts of leaves as well as the pollen grains become more distinct; pollen exines are very abundant.

Fiebelkorn, in the memoir already cited, gives sections showing the relations of Schwelkohle to ordinary coal. The bed at Grube 396 near Teuchern is only 6 to 7 meters thick, but at a little distance away it is 16, and, generally speaking, the whole bed is good. Some grains of coal are shown in the roof and the coal itself, especially in the upper part, shows alternating bright and dull laminæ. The section at this place is: Black earth, 0.60; loess, 7.50; Tertiary shale and sandstone, 6 to 8; impure coal, 0.30; Feuerkohle, 2.30; Schwelkohle, 0.50; Feuerkohle, 0.30 Schwelkohle, 4; Feuerkohle, 3; clay

201 C. W. v. Gümbel, "Beiträge," etc., pp. 146–148.

and roots, 2.50. The measurements are in meters. Fiebelkorn makes no reference to the Russkohle, which Stohr found associated with the Schwelkohle. The distribution of the latter is quite different from that seen by Stohr, for here the two types of coal alternate. The Schwelkohle changes into pyropissite toward the border of the trough.

The Oligocene coal of the Cologne-Bonn region on both sides of the Lower Rhine has been mined during a long period. Davis[202] has given a brief description of the deposit near Horrem, which shows the general conditions. The brown coal contains about 60 per cent. of moisture and is soft, at most, slightly consolidated in the bed. Fresh from the mine, it resembles rather woody, half dry peat or muck from a swamp forest. The included wood, mostly lignite, appears, even when dry, to be no more changed or carbonized than the wood found in many peat beds. When dry, it is still soft enough to be whittled easily, the chips being scarcely more brittle than those from kiln-dried wood of similar types. The deposits range from 32 to 328 feet in thickness, the average being about 72 feet. The coal is covered with relatively thin gravel and clay; this overburden is removed by stripping, and the coal is mined in open cuts. The moist brown coal, as it lies in the bed, is nearly black, unconsolidated and contains a large percentage of fine material, which is friable even when wet.

The brown coals near Bonn were studied long ago by Horner,[203] who saw four types at the mines: (1) A dark brown or black earthy substance, friable to pulverulent, rarely showing lamination and found usually as the upper portion of the beds; (2) a cemented mass, in which leaves and fragments of wood are mingled with the earthy coal; (3) wood in different stages of bitumenization, with all shades of color from light brown to black, the last approaching jet; (4) Papierkohle, highly bituminous, burning with bright flame, separating into laminæ as thin as writing paper and leaving a white ash; it is a mixture of earth and comminuted vegetable matter. It should be

[202] C. A. Davis, "Production and Uses of Brown Coal in the Vicinity of Cologne, Germany," U. S. Bureau of Mines, Techn. Paper 55, 1913, pp. 5, 6.

[203] L. Horner, "On the Geology of the Environs of Bonn," *Trans. Geol. Soc.*, II., Vol. II., 1836, pp. 449, 450, 459.

noted here that "bitumenization" as used by Horner and others of the earlier writers is practically synonymous with "coalification" of some French writers and refers merely to the extent of conversion.

The several kinds of coal are found at times in a single bed. The wood is ordinarily in fragments of inconsiderable size, but sometimes large stems are found. These, when prostrate, the usual position, are flattened; but trees have been met with, erect, with roots attached and the stems passing through some benches of the coal. Horner thinks that these may have been floated in, being held in position by the weight of the roots. One of these trees was 7 and another 11 feet in diameter; the depth of water in which such trees could be floated must have been considerable. The writer has seen great floods on great rivers and he has seen many floating trees with roots attached, but he has never seen one floating in vertical position, except where it seemed wholly probable that the roots were loaded with earth or stones. If these trees near Bonn had been floated in erect position, the inorganic materials ought to appear with them. Horner states that the wood is often well enough preserved to be utilized in timbering the mines. Pyrite is common and "amber" occurs in irregular balls. The wood, at times, is replaced in part or altogether with carbonate of iron.

The section of a shaft at Utweiler is as follows: Soil, 2 feet 6 inches; loess, 9 feet 5 inches; basalt, 31 feet 9 inches; indurated clay, prismatic, changed by the basalt, 1 foot; clay, coaly, neither slaty nor columnar, 6 inches; black pitch coal, in prisms, perpendicular to face of the basalt and with dolomite in the interstices, 1 foot 2 inches; small coal, 4 feet; brown coal or bituminous wood, unaltered and with structure preserved, contains in the lower portion kidneys of compact clay-ironstone, 8 feet 6 inches.

The influence of the basalt disappears within 7 feet. The constitution of the thick bottom coal recalls the condition so often seen in the lower part of peat deposits formed by encroachment upon forested areas.

Heusler[204] has given a full description of conditions in the Lower

[204] C. Heusler, "Beschreibung des Bergreviers Bruhl-Unkel und des Niederrheinischen Braunkohlenbeckens," Bonn, 1897, pp. 32–42, 45–52, 132, 161, 163.

Rhine region. The important localities are Deutz, at a short distance west from Cologne, Bruhl and Unkel, about 25 and 45 miles south from Cologne. Other areas are as far as Linz, a few miles beyond Unkel. Three types of coal are found in this region; Blätterkohle or Dysodil, Alum brown coal and the Earthy brown coal which is manufactured into briquets. The first and second, limited chiefly to the upper portions of the basin in the Siebengebirge, extend northward on the left bank of the Rhine to Friesdorf near Bonn, while on the right bank they are found as far as Spick in the Deutz-Runderoth district. Heusler asserts that the difference in these coals has no relation to age and is due merely to local conditions.

Blätterkohle occurs in isolated patches near Linz, Orsburg, Oedingen as well as on the Hardt, especially near Rott. The deposits are irregular and alternate with clay, sand and ordinary brown coal. Near Linz, three layers were seen, 1.1, 0.78 and 4 meters thick, each containing more or less of lignite-like coal and many remains of aquatic animals, 10 species having been recognized. Near Orsburg, three layers were seen, separated by clay and poor coal; batrachians of several genera are abundant in the coal. In an isolated basin, this section was obtained: Hard earthy brown coal with lignite, 0.94; bituminous clay, 0.63 to 1.10; laminated siliceous beds, with leaf impressions, 0.16 to 0.26; Blätterkohle and Polischiefer, 0.26 to 0.78; lignite, pyritous, with leaf impressions and remains of fish, 0.63 to 1.10; semi-opal, 0.16; Blätterkohle, laminated, pyritous, some lignite, nests of Polischiefer, fragments of plants, insects, fish remains, 0.31; gray, pyritous clay, 0.31.

The measurements are in meters. The association with diatomaceous earth is by means unusual. Near Oedenberg, the Blätterkohle is very thick, but is so mixed with infusorial earth as to be of little value. In the Rott area, at the Krautgarten mine, the finely laminated Blätterkohle, at the bottom, is separated by almost 2 meters of grayish-white clay from a meter-thick bed of ordinary brown coal above. In this mine, the coals contain remains of mammals, amphibia, fish, insects of six orders, with crustaceans, mollusks and polyps as well as abundant plant fragments of many types. Heusler's description

shows that here one has a good example of pond-filling. The same relations are seen on the left bank of the Rhine near Oedenberg and Liessen; at the latter, Blätterkohle attains its greatest thickness, varying from 3.8 to 16.5 meters. The total area of rich Blätterkohle barely exceeds one square mile.

Alum brown coal, like Blätterkohle, is confined to the more southerly portions of the region containing the Oligocene basins; it is found especially on the Hardt near Putzchen and Spick on the right, and near Godesberg and Friesdorf on the left side of the Rhine, where it is associated with layers of ordinary and lignite-like brown coal. The Hardt area is about 10 by 4 kilometers and includes the Rott deposit already referred to. The coal there is 3 to 4 meters thick, mostly earthy brown coal and so pyritous that the ashes are used in the alum industry. Midway, is a meter of lignitic brown coal, composed largely of prostrate stems. One of these, a conifer, was 1,600 years old, that being the number of annual rings. But erect stems are by no means rare; one mine near Bleibtreu yielded 35 such stems in a space of 10 acres, the diameter varying from 0.78 to 2.82 meters or about 9 feet. Pyrite replaces or penetrates much of the stems and roots. This lignite on drying becomes black and changes into a typical Pechkohle. The plants are mostly conifers and palms. The relations of the coals are shown in a section measured near Friesdorf, thus: Loam and river drift, 5.2; brown coal and alum clay, 0.94; clay and bituminous wood, 1.26 to 1.57; brown coal (lignite), 0.16; bituminous clay, 0.31; brown coal and lignite, 0.16; gray pyritous clay with lignite, 1.57; brown coal, 2.51; black alum clay, 1.57; Blätterkohle, 0.47; lignite, 0.47; earthy brown coal, 0.94; Blätterkohle, 0.63 to 0.94; earthy brown coal, 0.47; Blätterkohle, 0.63 to 0.94.

The association of Blätterkohle and pyrite seems, from Heusler's sections, to be very intimate at most localities. Nineteen species of plants have been recognized at Friesdorf, a large part of them belonging to genera well represented in swamp floras. Erect stumps are at Füssenich and Stockheim.

Alumkohle and Blätterkohle become rare northward and earthy brown coal, like the Formkohle of Sachsen, is the usual type. Lig-

nite or bituminous wood is present in this coal and the species are like those as on the Hardt and at Friesdorf; stems are especially well preserved in mine Friedrich Wilhelm Maximilian, near Turnich on the Erft, but many of the Hardt species are not represented. Deposits between the Rhine and the Erft are quite regular, with clay floor, containing more or less brown coal, and often have a clay roof, but very frequently the cover is a diluvial deposit of varying thickness, through which water passes into the porous brown coal and downward to the clay floor; this surface water injures the coal. There is no distinction here into earthy brown coal and Schwelkohle as in Sachsen; the only difference is in state of preservation—earthy and lignite-like brown coal. The former is from the soft parts of plants and is utilized in manufacture of briquets; the latter yields the lump coal. It is not known whether or not any Schwelkohle like that of Sachsen exists in this region. The Schmierkohle, found in the Hangenden near Bruhl, is said to yield a greater proportion of distillation products than does the underlying earthy coal; but it is much mixed with clay and has a great percentage of water; both water and ash decrease downward in the mass of the bed. The thickness in the area of earthy brown coal varies greatly and abruptly; in the Bruhl-Liplar region it is from 5 to 104 meters.

The Rhenish brown coal contains in many places what is known as oölite wood, the woody matter being largely or wholly replaced with spherules of carbonate of iron. In searching the survey coal collections at Berlin, Gothan[205] found a piece of the brown coal from the Donatus mine near Cologne, which contained similar spherules of carbonate of iron. Deposition had not been confined to the wood, but had reached into the actual peat. Specimens were obtained from Flügel, who had mapped the area, and they proved to be a part of the bed replaced with material like that of the plant-balls described by Stur. Gothan suggested the name of Torfdolomite. Microscopic examination by Hörich showed that the plant remains as a rule are not well preserved; they are so disintegrated that in many cases they cannot be identified. Roots are best preserved, probably because they

[205] W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Bd. XXXI., Teil II., 1910, pp. 38–44.

entered when the surrounding mass had already become peat. They show no sign of compression. Some fragments of stems show the great lacunæ characteristic of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

Von Gümbel[206] examined the Blätterkohle obtained near Bonn. After treatment with Schultze's reagent, it showed under the microscope only scattered plant cells, exines of pollen, algæ-like clumps and some very indefinite particles, which appear to correspond to bits of animal matter. The descriptions by Horner, v. Gümbel and Heusler show that Blätterkohle is of sapropelic origin and that it is wholly similar to Lebertorf.

De Serres[207] described Oligocene brown coals in southern France. At the important gypsum quarries of Lac, near Narbonne, he observed that between the beds of gypsum there are others, marly and containing remains of plants and fishes, the latter being freshwater forms. Dysodil, like that of Sicily, occurs in layers between thick beds of marl overlying the gypsum. It is typical, in paper-thin laminæ and burns quickly with an abominable odor. Between the laminæ are enclosed imprints of fishes and plants, the latter apparently dicotyledonous. The number of fishes is prodigious; there are not merely imprints, there is even the actual substance, at times, in the marl beds and between the dysodil laminæ. The lower part of the section is mostly a limestone mass with lignites (brown coal). The succession near Caunnette is: (1) Calcareous sandstone, belonging to the compact gray macignos, exploited at Carcassone, 40 to 50 meters; (2) freshwater limestone, fissile, whitish, without trace of organisms; (3) limestone, very compact, with many fluviatile shells, *Lymnæa* and *Planorbis* being most abundant, 10 to 20 meters; (4) argillaceous limestone, allied to the macignos, 2 to 4 meters; (5) very bituminous freshwater limestone, divided by thin layers of hard, black, lustrous lignite, 10 to 12 meters; (6) carbonaceous shale, blackish, "nerf" of the workmen, contains numerous

[206] C. W. v. Gümbel, "Beiträge," etc., pp. 146–148.

[207] M. de Serres, "Observations géologiques sur le Département de l'Aude," *Soc. des Sci. Lille*, 1835, pp. 439–471.

Lymnæa and *Planorbis;* (7) first lignite, friable and of inferior quality, often has *Lymnæa* and *Planorbis* in top portion, 0.50 to 1 meter; (8) blackish carbonaceous shale, with river shells and kidneys of freshwater limestone; (9) second lignite, better than the first, but more irregular, 0 to 0.50 meter; (10) blackish carbonaceous shale with freshwater limestone, holding *Unio, Lymnæa* and *Planorbis;* (11) freshwater limestone, with more or less of lignite, 10 to 15 meters; (12) third lignite, very irregular, rarely thick enough to be mined; (13) irregular freshwater limestone resting on the nummulitic limestone.

Unio and *Cyclas* occur, though somewhat rarely, in the Caunnette lignite. Near the village of Songragnes, de Serres found lignites of apparently the same age, associated with blackish, bituminous marls, which contain much pyrite and some jet. The lignite encloses many nodules of amber, at times as large as a hen's egg. Some are translucent, others opaque, but all yield succinic acid. The noteworthy feature is the mass of freshwater limestone, with minimum thickness of 250 feet and interrupted only by freshwater carbonaceous shale with lenses of brown coal.

The Eocene Coals.—Molengraaff[208] has shown that coal-forming conditions existed in central Borneo during the Eocene. The coal is thin at most localities but occasionally it is of workable thickness. One exposure on the Mandai River has a bed, one meter thick, enclosed in shale and rich in carbonized tree trunks, which are partly silicified. Clayey layers of an overlying sandstone contain many impressions of leaves. On the Tabaoeng River, he saw a bed in three benches, 4, 1.40 and 2 meters respectively, separated by thin partings of shale and clayey sandstone, in which are concretions with plant imprints. The lower benches are fissile and evidently of poor quality, but the top bench consists of black pitch-coal, which seems to be good. These localities are within one third of a degree north and south from the equator. The sandstones of this coal-bearing group, not more than 40 meters thick, have grains of coal at many places and the associated volcanic tuffs, of undetermined age,

[208] G. A. F. Molengraaff, "Geological Explorations in Central Borneo," 1902, pp. 59, 60, 93.

contain erect and prostrate stems, which, according to Molengraaff, are distinctly *in loco natalis*.

Hutton[209] described important deposits of brown coal in New Zealand, which belong to the Upper Eocene. At one locality he saw two beds, 6 and 2 feet, underlying and overlying shales with leaves; the dip is 25 degrees. In another valley, the upper bed is 10 feet thick and has dip of 10 degrees. The mining operations are extensive and the coal everywhere is rich in "ambrite." In a later publication, he refers to bituminous shale near Dunedin and to a similar shale near Orepuke. That near Dunedin varies in thickness from 6 feet to 18 inches within a distance of 20 chains—a pronounced lens. It yields 42 gallons of crude oil per ton. The Orepuke shale is equally rich.

The coal of Häring, in the Tyrol, and its peculiarities have attracted notice from numerous students. Reuss[210] stated that the coal rests on gray to brown shale-clay, which becomes increasingly coal-like as it approaches the coal; at the same time it becomes more calcareous and finally passes into a crumbling coal, mixed with marl. It is rich in shells, *Helix, Planorbis* and a small bivalve, usually so crushed as to be unidentifiable. Some layers seem to be composed wholly of these shells; no remains of plants were observed. The coal, at times 30 feet thick, varies from Pechkohle to shining black "Schieferkohle" and nowhere shows any woody structure. The benches are 3 to 6 inches thick and the partings often consist of bituminous limestone, with nests of more or less shell-bearing limestone. The dip is from 30 to 35 degrees. The roof is a thin-bedded fetid limestone with many indistinct bivalves and, more rarely, *Fusus* and *Rostellaria*. It contains also abundant fragmentary remains of plants, among which *Salix, Erica,* palms and other forms have been identified.

Von Gümbel[211] speaks of this coal as embedded in undoubted marine marl deposits, containing both brackish water and freshwater

[209] F. W. Hutton, Reps. New Zealand Geol. Survey for 1871–72, pp. 107, 108, 181; "Geology of Otago," p. 110.

[210] Reuss, "Geognostische Beobachtungen durch Tyrol," *Neues Jahrbuch,* 1840, pp. 162–164.

[211] C. W. v. Gümbel, "Beiträge," etc., pp. 149, 150.

as well as land shells, along with remains of plants. The peculiar features of the deposit led him to recognize a condition analogous to that of cedar swamps on the low border of a bay. Treated with Schultze's reagent, the coal shows under the microscope that the bright layers are composed of leaves, epidermis and plant-parts with parenchymatous structure. The dull layers are more intricate. Faserkohle is quite abundant.

Haidinger,[212] 20 years earlier, had described a characteristic fragment of mineral charcoal obtained at Haring. He thought it probably an inclusion in the peat from which the brown coal was formed. This Faserkohle passes so gradually into the enclosing glance coal that Haidinger was inclined to believe it a case of external conversion into coal. At the same time, the Faserkohle is interwoven with vein-like lines of bright coal, which in his opinion could have been introduced only in a gelatinous condition like that of dopplerite.

Heer[213] notes that, near the Dürnten Schieferkohle area, a deposit of lignite occurs in soft sandstone of the Molasse. It often contains tree trunks but other parts of plants have become indistinguishable. Yet one finds marsh plants in the marls overlying the lignite, while the underlying limestone contains *Unio* and *Planorbis*.

The Bovey Tracey deposits in Devonshire, England, were described in great detail by Pengelly.[214] They had been subject of discussion during many years and the associated clays had been utilized on an extensive scale. The excavation, at the time of Pengelly's examination, was more than 100 feet deep, 350 feet wide and almost 1,000 feet long. His section, greatly condensed, is: Clays, sandy clays, thin sands and 4 beds of lignite, 7 to 15 inches thick; this lignite is poor, loose, brittle, woody; the clays are dark to gray, with streaks and fragments of lignite, 37 feet 7 inches; lignite with partings, 14 feet of lignite in 5 benches with about 7 feet of clay in the partings; the uppermost bench is more or less wood-like and at the bottom is a mass of dicotyledonous leaves; two of the clay part-

212 W. Haidinger, *Verhandl. k. k. Geol. Reichsant.*, Bd. XIV., 1864, p. 241.

213 O. Heer, "The Primæval World of Switzerland," Eng. Trans., London, 1876, Vol. I., p. 32.

214 W. Pengelly, "Lignite and Clays of Bovey Tracey, Devonshire," *Phil. Trans. Roy. Soc.*, Vol. 152, 1863, pp. 1019–1038.

ings have streaks or fragments of lignite; the thick bottom bench is No. 25 of Pengelly's section, 20 feet 11 inches; clays and sands, stems and leaves are abundant in the upper half and thin streaks of lignite were seen in the lower part, 44 feet 1 inch; lignite with partings, 17 feet of lignite in 9 benches and 3 feet 2 inches of clay in the partings; the lignite benches are 3 inches to 4 feet thick, 20 feet 9 inches.

Roots descend from the lowest bench of the upper lignite into the underclay and the coal of that bench consists very largely of fronds of great ferns associated with leaves of other plants. The lower bed shows noteworthy variation in its benches. The third, descending, is woody and somewhat charred; the fifth and sixth are very hard and compact, not so tough as some of the others. The bottom bench is divided by a thin parting of "charred lignite" into an upper portion, 9 inches thick, which breaks into "irregular glassy pieces," and a lower portion, 3 feet 3 inches, which is hard light brown, less heavy than the ordinary lignite, is brittle woody and looks like ordinary coal. Mineral charcoal is present in all the benches. Of the about 50 species of plants recognized by Heer, Sequoias are most abundant and they form the greater part of one bed. Conybeare[215] has remarked that, in the Bovey Tracey area, one can see "the most decided wood pass into a substance no wise differing from common coal in chemical characters."

The Lower Tertiary coals of the United States of America are of great economic importance. They are of all grades from woody lignite to bituminous, even coking coal, and anthracite; and all are utilized. The basins and the fragments of basins which have escaped erosion are mostly in areas bordering on the Rocky Mountain region; but besides these there is a very extensive area in Texas and petty deposits are found in a few other localities west from the Mississippi Valley.

The deposits carrying brown coal in Texas have been grouped by Dumble[216] into the Timber Belt, the Yegua and the Fayette, the last

[215] W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, p. 345.

[216] E. T. Dumble, "Report on the Brown Coal and Lignite Deposits of Texas," Austin, 1892, pp. 125, 135, 151, 165.

being the newest. Coal beds from a few inches to 10 or more feet thick are numerous in the Timber Belt. The enclosing clays, in many cases, are extremely dark and contain much silicified wood as well as lenticular masses of iron carbonate. Silicified wood is abundant in the Yegua.

Penrose,[217] in a publication of somewhat earlier date, described the lignite as occurring in a broad area, which in some portions extends eastward to within 150 miles from the Gulf coast. He separated the rocks into two divisions of which the upper may be Miocene. The coal beds are often double, as shown by a section in Robertson county, where the benches, 12 and 2 feet thick, are separated by 2 feet of clay. This is the important bed of the lower group and its coal is lignite, black, friable and woody. The upper group, along the Colorado River, has beds one to 10 feet thick, some of which contain masses of wood, including tree trunks partly silicified, partly lignitized. The coals of this upper group are all in lenticular deposits. Texas brown coals hold not only trunks, branches and leaves of trees but also reeds and other forms characteristic of swamp vegetation. In some beds, the coal shows distinct vegetable structure, but generally the mass of the material has been so thoroughly converted that no trace of structure is visible to the unaided eye. Frequently the coal is amorphous and soft, while at others it is hard, black, brilliant, with either cubical or conchoidal fracture—but all possible gradations exist between these extremes. The rocks throughout are undisturbed and coal of both types appears often in a single section. At the San Tomas mines, 25 miles above Laredo on the Rio Grande, a coal bed was seen with this structure: lignite, 2 inches; clay, 4 inches; coal, 1 foot 3 inches; black clay, 2 inches; coal, 1 foot 3 inches. The underlying clay contains just below the coal streaks of lignite—a faux-mur. The coals are massive glossy black and with conchoidal fracture, without trace of vegetable texture; but the thin top bench is a true lignite with the plant texture well-preserved. Kennedy[218] in the same state found

[217] R. A. F. Penrose, Jr., "Preliminary Report on the Gulf Tertiary of Texas," First Ann. Rep. Geol. Survey of Texas, 1890, pp. 26, 43, 52, 53, 94, 95.

[218] W. H. Kennedy, "Harrison County"; J. H. Herndon, "Smith County"; Second Ann. Rep. Geol. Survey, pp. 155, 156, 267.

at one locality, two embedded trunks, 16 and 20 feet long, 18 and 20 inches thick. The shorter stem was silicified throughout but the other was so at only one end, lignitized at the other; the conditions merging imperceptibly. At one place he saw a silicified stump, of which the interior had decayed before, silicification began. Herndon observed that within Smith county the coal beds are lenticular; the coal is brown to black, earthy to hard and frequently contains resin. Phillips and Worrall in 1913 estimated the brown coal area of Texas at not less than 60,000 square miles. The coal in many mines is very tender and the loss in screening even the freshly mined coal is very serious.

D. White[219] studied two typical localities in the Texas field, whence a lignite, not very wood-like, is obtained. The deposit near Hoyt in Wood county appears to have been made in a bayou or lagoon of irregular form, one half to three quarters of a mile wide, and it thins toward the margins. The floor is buff sandy clay, traversed locally by large roots of land plants, clearly in place. The coal, with maximum thickness of 9 feet, is dark brownish black, fairly well bedded, mostly moderately xyloid but with many lenses of brownish, more massive coal, with conchoidal fracture, waxy to satiny look, and amorphous; zones of well-laminated coal were seen. These, darker than the main benches, show cuticles and small woody particles, like much Palæozoic coal. The lenses are more or less canneloid. Amber is present in the upper part of the bed, which is distinctly xyloid; mineral charcoal is not abundant, but there is an inch parting which consists of densely matted fragments of charcoal. There were large trees, one log, partly silicified and somewhat flattened, was more than 70 feet long. The roof varies; at times it is "dirty coal," at others it is a bony coal and occasionally it is a carbonaceous clay, several feet thick.

The deposit near Rockdale was laid down similarly in an estuary or bayou, 10 miles long and one half to one mile wide. Two beds are worked by many owners in this area. The floor of the upper bed is gritty clay overlying sand and well-filled with roots, traversing the old soil in all directions at angles to the bedding; some of these are more than 3 inches thick. The bottom bench of coal con-

[219] D. White, "Origin of Coal," Bureau of Mines, Bull. 38, 1913, pp. 12–19.

sists of one to 3 inches of "black jack," a stiff, black coaly material with fragments of wood and stems. The coal is clean and solid for 6 feet; above that it is streaked with thin washes of white sand and dirt and irregular lenses of sand which seem to be in ripples. Higher, the sand washes are thicker and at length predominate, with intervening black muds, carrying waterworn vegetable materials. Above this is compact laminated clay, 3 feet thick, with many stems and traces of what appear to be roots. The upper part of the dirty coal, where it begins to be laminated, is rather distinctly marked with roots, branching rather irregularly downward and some of them appear to have extended a long distance into the coal below. Many of these seem to have rotted and the cavities to have been filled with white sand and clay, disfiguring the coal. Amber or fossil resin is abundant in some layers and the coal has joints, 10 to 12 feet apart. The lower bed rests on drab clay, filled with roots in place, which is covered by a thin layer of old humus, followed by more than 6 feet of black, splintery coal with conchoidal fracture, becoming dirty and laminated on top. On this rests light-colored clay with carbonized roots, 10 to 30 inches thick, which is succeeded by 6 to 18 inches of coal. Tree fragments are fairly common in this lower bed. White's description shows that the faux-toit is characteristic at both Hoyt and Rockdale; and that the faux-mur is present throughout at Rockdale.

At Lester, in Ouachita county of Arkansas, the lenses of canneloid coal are such that White regards them as presenting the lignite stage of cannel. The locality is in the Camden coal field, which is a small, irregular and very shallow basin with extreme dimensions of 7 by 15 miles. The rocks are unconsolidated sands and clays with some ferruginous sandstone. There is one workable coal bed, varying from 2 feet 6 inches to 6 feet, owing to the uneven floor. This floor is usually clay and holds no roots, except in one place, where it is sand and shows many roots in place. In one portion of the field, a carbonaceous mud forms the bottom of the bed and contains lignitized stems and twigs with fragments of ferns and dicotyledons. The roof is a light gray plastic clay. The coal or canneloid lignite has the general structure and appearance of a somewhat impure

cannel, is so soft and tough that it can be cut with a knife. It is free from foreign matter except at the bottom; occasionally a thin carbonaceous mud, with slender stems as jet-like fragments covers the coal and a thin xyloid bench was seen midway in the bed. The coal has high volatile, high illuminating power, high heating efficiency and gives copious yield of oil when distilled—the best yields 38 gallons per ton.

Thiessen,[220] in discussing this Lester material, says that it consists of vegetable débris from a herbaceous flora, but contains bits of angiospermous and gymnospermous wood, showing that a wood-flora existed. Everything is so well disintegrated and decomposed that very little is recognizable except the most resistant parts of plants. Exines of spores and pollen grains, resins and an undetermined waxy or resinous substance are conspicuous. The interstices are filled with more finely macerated parts of those constituents. Spores of fungi are present but are not abundant. The spore exines are mostly those of ferns, there being few from lycopods, while the pollen is both angiospermous and gymnospermous. Spores and pollen grains make up about 30 per cent. of the mass and are associated with abundance of cuticles. The resinous bodies are of two kinds, one, the lighter in color, is the more refractive and is paraffin-like in consistency; the other is less abundant and less refractive.

Eocene coals of the Rocky Mountains and adjacent areas are especially important within the states of Utah, Wyoming, Montana and North Dakota, where mining operations have been extensive at many places. The citations which follow are mostly from the more recent publications, as those of earlier date were made when opportunities for observation were not so good and dependence had to be almost wholly on natural exposures.

In one area within Utah, Richardson[221] found the coal between beds of freshwater limestone, black bituminous, containing abundantly the crushed shells of *Sphærium* and *Physa*. One bed is 36 feet thick, with 4 partings, of which the thickest is but two inches and a half. The rocks are faulted and the dip is from 10 to 15

[220] R. Thiessen, "Microscopic Study of Coal," the same, pp. 232–238.

[221] G. B. Richardson, "Coal in Sanpete County, Utah," U. S. Geol. Survery, Bull. 285, 1906, pp. 281.

degrees. The coal, as far as proximate analysis shows, is a very fair bituminous coal. The deposit is irregular and, in one direction, thins away within two miles.

Eocene deposits cover a great part of eastern Wyoming. Taff[222] found that, in the Sheridan coal field, the upper member of the Fort Union, about 2,200 feet thick, consists of friable, loosely consolidated sandstones, coal beds and slightly indurated shales, all with gentle dip, seldom exceeding 4 degrees. The coal beds are in three groups; the lower or Tongue River contains ascending the Carney, Monarch, Dietz, No. 3, No. 2 and No. 1, Smith and Roland coal beds, all of which are of workable thickness, the thinnest being 5 and the thickest somewhat more than 30 feet thick. The Intermediate group contains some lens-like coal beds, which at some places are of sufficient thickness for mining. The Ulm group or highest has two beds 16 and 12 feet. Nearly all of the beds are at least double and some of the highest beds are broken by partings. The coal is apparently almost uniform throughout; the weather attacks all alike. The only important distinction is that coal from the Intermediate and the Ulm has somewhat more water and shows the texture or fiber of some plants, whereas that from the Tongue River, though high in water, shows no woody texture to the naked eye. The thicker beds for the most part are without lamination; silicified wood is not rare.

Wegemann[223] examined an area contiguous to that studied by Taff in northeastern Wyoming and continuous with the extensive fields of eastern Montana and western Dakota. The exposed rocks, about 1,000 feet thick, belong to the upper part of the Intermediate and lower part of the Ulm, as defined by Taff. Wegemann saw many local unconformities and great variations in the rocks. A notable feature is the coarse sandstone filling channels in beds of coal and shale, due clearly to subaërial erosion. The cross-bedded sandstone denoting shallow water, the fine shale, proof of quiet water, the numerous coal beds and the repeated evidence of sub-

[222] J. A. Taff, "The Sheridan Coal Field, Wyoming," U. S. Geol. Survey, Bull. 341, 1909, pp. 127–130, 133, 144–147.

[223] C. H. Wegemann, "Barber Coal Field, Wyoming," U. S. Geol. Survey, Bull. 531, I., 1913, pp. 11, 12, 19.

aërial erosion are regarded as marking the presence of a great river, meandering over broad flats.

The coal is dull black with vitreous streaks and is brittle; but the woody origin is still distinct and fragments of *Sequoia* are abundant, associated with leaves of dicotyledonous plants. Trunks and stumps, erect or prostrate and partially silicified, embedded in the coal or projecting from the sandstone, are by no means rare. Coal beds are usually less variable than the other members of the section. The Healy coal of the Ulm group has been traced in an area of about 600 square miles, but the name designates a horizon rather than a coal bed. Where it is a single bed, it varies within short distances from a few inches to 18 feet, but often it is represented by a series of beds in a vertical section of 50 feet. This horizon is exceptional in extent, other beds, as a rule, having very limited area. One, 15 feet thick, quickly thins to a few inches and disappears; often a bed thins away and another is seen in the section at a little above or below its place. These are merely overlapping lenticular deposits. Contemporaneous deposits of coal are frequently separated by barren spaces. That these conditions, described in detail by Wegemann, are characteristic throughout Wyoming is evident from the incidental references by other observers.

Eocene deposits cover much of eastern Montana, extending northward across the state from Wyoming into Canada and eastward into North Dakota. The isolated basins of eastern Montana have been studied by several geologists. Woodruff and Woolsey[224] examined fields on the western side of the area, where they observed conditions hardly differing from those seen in Wyoming. Woodruff states that the coal beds with maximum thickness of 5 to 10 feet were evidently formed in basins. Many of them have carbonaceous shale, at times containing streaks of lignite, as floor and roof; at one mine he obtained *Unio* in the roof. Woolsey remarks that the coal beds in his area are very irregular and are lenticular. Resin is especially abundant in the Bull Mountain field, where the beds are

[224] E. G. Woodruff, "The Red Lodge Coal Field, Montana"; L. H. Woolsey, "The Bull Mountain Coal Field," U. S. Geol. Survey, Bull. 341, 1909, pp. 94–97, 103, 104: 62–77.

broken by many partings and the coal, more or less laminated, is jointed.

A small area examined by Rogers[225] is farther northeast; there the more indurated rocks of the lower division show mud cracks, cross-bedding and rippled surfaces. The coal of that division is brittle and fairly compact, though in some cases the woody texture is distinct. The coal of the upper division is mostly lignitic; but this distinction is not absolute, for vitreous coal is found in some of the higher beds and woody lignite is by no means uncommon in the lower division. Throughout, the coal beds are irregular; in all parts of the section, beds thin out and others appear at 8 or 10 feet higher or lower, so that Rogers is compelled to recognize horizons rather than contemporaneous separate deposits.

Farther eastward, beyond the Yellowstone River, one reaches the great lignite area with its numerous independent basins, which were examined by Bowen, Herald, Vance, Stebinger and Beckly.[226] The southern or Baker field shows mostly lignitic coal, woody in structure, brown and tough; the beds are broken by partings of considerable thickness and the benches are seldom of workable thickness. In the Terry field, all the deposits are irregular; the coal beds vary abruptly in thickness and character, often changing from coal to shale within a few yards. Even the comparatively persistent bed at the base is so irregular that Herald is inclined to speak of it as a "lignitic zone." The lens-like form of the deposits is characteristic throughout. The Glendive area is somewhat farther north. The lowest coal bed is apparently continuous along an outcrop of 150 miles, but Hance found it extremely variable in thickness and quality. Its coal is inferior to that of the bed, 50 to 150 feet higher. In places, two sets of joints are distinct.

Stebinger, after study of the Sydney field, which extends to the Canadian border, was not willing to admit that the lens-form is a persistent feature, though he recognizes fully the abrupt and ex-

[225] G. S. Rogers, "The Little Sheep Mountain Coal Field." U. S. Geol. Survey, Bull. 531 F, 1913, pp. 9, 11, 19, 20, 23, 24.

[226] "Lignite in Montana." U. S. Geol. Survey, Bull. 471 D, 1912; C. F. Bowen, pp. 21, 38, 39; F. A. Herald, pp. 56, 60, 62, 78; J. H. Vance, pp. 89, 92, 97, 98; E. Stebinger, pp. 106, 107, 115; A. L. Beckley, 152.

tensive variation in coal beds. Two beds appear to be really persistent for long distances; he had traced for 120 miles one which he regards as the equivalent of a bed in North Dakota. The coal is lignitic throughout, though it often resembles sub-bituminous. After weathering, the grain of the wood disappears, the color changes to black and the material is no longer tough, but is brittle. The greater part was formed from trunks of trees and fragments of wood; even entire logs, usually prostrate, can be traced on the fresh face of a mine. Coal in the lower 500 feet of the formation is less woody in appearance than that from the upper 500 feet. The extreme variability of the coal beds led him to infer that conditions were very unstable in the old moors. Beckly found the lignite very tough and wood-like in the Culberston field.

In considering the remarks on Montana areas, one must bear in mind that in most of the region the studies have been confined to natural outcrops and that tracing of the beds has been made in considerable areas by means of clinker lines, the burned outcrops. Extensive mining operations are concentrated, the localities being very few. The intervals between coal beds are reported as varying greatly. Speaking in a general way, it would seem that the measurements are too few for determining whether or not such variations are merely irregularities. The comparatively few detailed measurements are not enough to show the relations of the several benches of any bed in a large area. There is enough, however, to raise doubt respecting the actual continuity of the beds for any considerable distance.

Leonard,[227] in his synoptical description of the Dakota region, calls especial attention to the great variability of the accompanying rocks. The coal seams are from one inch to 33 feet thick and usually they are not persistent in extended areas. A seam may be pinched out or perhaps it may be replaced by another at the same or a slightly different horizon. Two seams may overlap, so that while both are to be seen in one section, only one of them may be present at half a mile away. Some can be traced in the river bluffs for

[227] A. G. Leonard, "North Dakota-Montana Lignite Area," U. S. Geol. Survey, Bull. 285, 1906, pp. 316–330; A. G. Leonard and C. D. Smith, "The Sentinel Butte Lignite Field," Bull. 341, Pt. 2, 1907, pp. 15–35.

several miles, but sooner or later they disappear. In Dakota, the coal is largely wood-like, tough and showing the grain; flattened trunks of trees frequently differ little from wood except in color. Often, the same seam is composed of alternating layers of tough, brown lignite and of black, lustrous more brittle material. The character of the coal changes toward the west; in Dakota it is woody and brown, but just beyond the Montana line it is largely lustrous; the same feature was observed still farther west at Glendive.

Leonard and Smith saw 9 coal beds of workable thickness, the lowest of which, according to Beckly, is about 400 feet above the Glendive bed—at the bottom of the Eocene. As result of broader studies, they modify the general assertion of lens-form and assert that some of the important beds have been traced continuously for 24 miles, while they have been correlated with much certainty for greater distances. Dips are very gentle throughout the region examined. Pockets of lustrous, black, textureless and brittle coal are scattered through many seams and are less pure than the lignite.

The Eocene coals continue into Canada, where they become less important and are overshadowed by those of the Mesozoic.

D. White[228] examined several localities within the Dakota region and gathered material, which was studied microscopically by Thiessen. The observations are so important that they must be given in full abstract. The coal bed, mined at Wilton, North Dakota, is near the bottom of the Fort Union or early Eocene, a freshwater formation, which stretches, in almost horizontal condition, from central North Dakota westward to the foot of the Rocky Mountains. At Wilton, the floor of the bed is white plastic clay, 4 to 5 inches thick, resting on white sandy clay and occasionally showing large roots in the place of their growth. The thickness of the coal is said to average about 7 feet, with a maximum of 14. The lowest 18 inches is a good lignite, broken by very thin clay partings; a half inch parting of mineral charcoal appears at several feet higher. A thin bench was seen, consisting of laminated coal, which resembles the bituminous types of Palæozoic and Mesozoic. The top coal includes a bony bench, formed apparently from dead aquatic or far-decayed vegetation mingled with mineral sediments, and a brownish

[228] D. White, "Origin of Coal," pp. 7–11.

layer near the bottom appears to contain grasses, stem fragments and chips of wood. The basal coal is almost black as are also the lenses or local layers of amorphous coal. When freshly mined, the mass is distinctly woody, tough and somewhat elastic; some large pieces are brownish-yellow as if from a recent bog. Often the "brown wood of a single piece verges into black, and even into a typical glossy lignite, having a conchoidal fracture and approaching jet. It is notable that the probable saturation with decomposition products in solution, that has produced the jet-like wood, resembling black vulcanized rubber, has not penetrated to the center of some of the fragments, which are inwardly brown or even yellow." Parts of some fragments appear to be charred while other parts are brown and woody. Wood makes great part of almost all the hard pieces examined, and logs, lying in all directions, are frequently in masses. To the naked eye, resin appears to be present in small quantity; silicified stems rarely occur.

The noteworthy features of the bed at Wilton, as summarized by White, are (1) an underclay, seemingly penetrated by roots; (2) evidence of periods, when herbaceous vegetation held the ground in certain areas and produced thin benches; (3) evidence of periods of great accumulation of wood of arboreal size; (4) relative scarcity of thinly laminated earthy or amorphous lignite (peat), this being dependent on the more or less nearly complete decay of the plant tissues; (5) evidence of frequent near approach to asepticity in the water body, so that decay seems to have been arrested quickly; (6) evidence that the surface was exposed at times to air, leading to formation of mineral charcoal. He thinks that the high water-content is a legacy from an unreduced or immature brown peat and also that the accumulation of logs, decayed only in part, indicates rapid growth of the coal.

The coal at Glendive, Montana, is very near the bottom of the Fort Union; it has been followed in a northerly direction for more than 50 miles. The fuel is dull black lignite, containing a large proportion of wood, sometimes in great slabs, both dull and jetified. No roots were seen in the underclay; mineral charcoal is present in a layer as well as in scattered pieces and the coal contains very many

lumps of amber-like resin, some of them apparently still attached to the wood. At the bottom of the bed there is a thin layer of dirty lignite.

The coal at Lehigh, North Dakota, is in the upper portion of the Fort Union, and the bed mined there is but one of many, 20 seams having been counted in one short section. Most of these had been laid down in freshwater swamps; usually they rest on underclays and frequently they have clay partings. The thickness is reported as varying from 6 to 8 and even more feet, "the greatest developments being found in the hollows of the floor, the coal thinning on all sides to the 'rise,' though on the whole it is relatively regular in bedding and thickness." The bed is singularly clean. The lower bench is free from all partings, except the charcoal layers, which are apt to be sulphurous. It is a dark brown, earth-colored lignite in which the large amount of wood is noteworthy. The grain of the wood is conspicuous as are also compressed trunks of trees with their branches, which compose about 75 per cent. of the whole. Some logs are gnarly, one to two feet wide and several inches thick. Some fragments are fully jetified, others partly so and others still, not at all, aseptic conditions having prevented decay. There seems to be little resin. The roof and floor could not be studied, but roots were observed in underclays of some higher beds.

Thiessen[229] studied the coals of Montana and North Dakota, collected by D. White. They are all xyloid lignites, consisting of 75 to 85 per cent. of woody material. The interstices are filled with débris from a large variety of plants and parts of plants, a binding stuff or "Fundamental matter." This semi-decayed, macerated, disintegrated material, composed of wood, parts of angiospermous and gymnospermous leaves, herbaceous stems, bark, roots, exines of spores, pollen, resinous and waxy bodies, cuticles, is cemented by matter, which apparently was once plastic. Spores and pollen exines form a considerable portion of the mass. The trunks of trees are wholly of conifers, mostly Taxadineæ and Cupressineæ, with a few Abietineæ, there being no stems certainly recognizable as dicotyledonous.

He compares the conditions with those observed by him in peat

[229] R. Thiessen, "Microscopic Study of Coal," pp. 221–232.

deposits within Michigan and Wisconsin, where *Thuja occidentalis* (white cedar), *Larix laricina* (tamarack) and *Picea mariana* (black spruce) abound, the *Thuja* being predominant. The growth is so dense that only a thin mat of mosses, liverworts and lichens with an occasional herbaceous plant can grow on the ground beneath. The peat, on which the forest stands, consists of logs and branches, lying in all directions, much changed and more or less macerated. The interstices are filled with "débris, in which macerated parts of stems and branches, cone scales, leaves, thalli of mosses and liverworts, pollen grains, etc., are plainly recognizable.

Nothing of algal origin was found in these coals.

The important coals of Eocene age on the Pacific coast are those in the state of Washington, where one finds all types of coal from peat-like lignite to hard dry anthracite, passing into graphite. Much of the area was studied years ago by B. Willis and G. O. Smith; but since their examination, mining operations have been developed on a large scale at many places, so that it seems best to utilize in this synopsis only the latest results.[230]

The Cowlitz River, rising in southern Lewis county, flows across Cowlitz county to the Columbia. The coal in this area is lignite throughout except where changed by eruptive rocks. At one locality, Collier saw a bed, more than 20 feet thick, as exposed in two open cuts, and composed of material "apparently little better than peat." It contains fragments of wood, which, though brittle, are flexible and elastic. Similar coal was seen in Lewis county, six miles away toward the northwest. The wood is so well preserved that one can whittle it easily. This fuel has little ash and is given to spontaneous combustion. Throughout the area, the coal is so woody that mining is difficult.

Some anthracite has been found on the eastern side of Lewis county, but most of the coal in that area is semi-anthracite to semi-bituminous: the beds are thin and the ash is high. At about 30 miles

[230] E. E. Smith, "Coals of the State of Washington," U. S. Geol. Survey, Bull. 274, 1911, pp. 152, 158, 161, 167, 180, 190; G. W. Evans, "Coals of King County, Washington," Washington Geol. Surv., Bull. 3, 1912, pp. 28, 29, 31–33, 59, 65, 116, 152; A. J. Collier, "Coal Resources of Cowlitz River Valley," U. S. Geol. Survey, Bull. 531 L, 1913, pp. 9, 12.

farther west, in the Ladd area, where dips vary from 32 to 40 degrees, the coal varies from anthracite to bituminous, both coking and non-coking; but in the Mendota-Chehalis area, about 30 miles farther west, the coal is sub-bituminous. Some of the beds in this latter area are more than 9 feet thick; the coal is massive, banded and, in some mines, is on the border line between sub-bituminous and lignite. The dips are from 12 to 54 degrees, mostly above 30. At Mendota, where the coal is grayish-black and low grade sub-bituminous, irregular lenses of soft, cannel-like coal are present. When freshly mined, these are black, but they quickly become brown on exposure. They contain so much volatile matter that when ignited by a match they burn like cannel with a long smoky flame.

In the northern part of Pierce county, 30 to 50 miles north from the Ladd area of Lewis, mining operations are extensive. Two beds at Burnett have laminated, good bituminous coking coal, which has been utilized in manufacture of illuminating gas. The dip is 45 degrees. At Pittsburg, two beds with dip of 58 to 60 degrees are mined and yield bituminous but non-coking coal. At Wilkeson, three beds, with dips of 20 to 60 degrees in different parts of the same mines, give a bituminous coking coal, well laminated, with varying ash in the several benches. The jointing is close and there is not much lump coal. At Carbonado, 12 beds have been worked, all of them more or less broken by partings and with dip of from 20 to 60 degrees. The coal is dense and bituminous, comparing very favorably with good bituminous coal from the Coal Measures. The lowest three beds are described as coking. At Montezuma, the coal is coking, semi-bituminous and the dips are 65 to 70 degrees. Resin occurs in low-grade sub-bituminous and to some extent in the higher grades within Lewis, Thurston and King counties.

Evans made detailed study of the coals in King county. Those in the western part have much moisture and are sub-bituminous, but farther east the bituminous type is not uncommon. The newer coals are more nearly lignitic than those from the lower beds. Throughout the whole column of about 8,000 feet, one finds great variation in composition and, far too often, the ash is so abundant as to make the coal worthless commercially. Several beds are quite regular in

occurrence within considerable spaces, but they change so abruptly in thickness, structure and composition that correlation in the different areas is impossible; the associated rocks are equally variable. The floor is usually clay or shale, often carbonaceous, but occasionally it is sandstone. Some parts of the county lost much coal during formation of pre-glacial valleys, now filled with glacial drift; while several coal beds suffered much from contemporaneous erosion and were replaced in considerable areas with sandstone. Evans notes tree trunks extending from the coal into the roof. D. White,[231] when at Rentoul in 1908, saw "kettle bottoms," or erect stumps of trees, 6 to 18 inches in diameter, standing directly on the coal, with black shale and coal filling the casts of the decayed boles. The coal is distinctly xyloid and jetified wood is strongly in evidence. Evans found a silicified erect stump showing the annual rings. Thiessen[232] ascertained that the coal collected by D. White contains a great proportion of débris, the quantity being almost equal to that of the woody matter. The woody component is coniferous and resinous; the débris is very resinous, apparently almost one half of its mass consisting of such material. Exines of spores and pollen are rather abundant but cuticles are rare.

The province of British Columbia, Canada, adjoining the state of Washington at the north, has a number of isolated coal basins, mostly of small extent. The available knowledge respecting the region has been digested by Dowling,[233] from whose work this synopsis is taken. It seems probable that the deposits are of Oligocene age in many of the places where the coal is economically important. In the Tulameen district, according to C. Camsell, the coal-bearing rocks occupy a basin in the older rocks, with an area of about 5 square miles. The section measured is about 2,500 feet and the middle portion, 460 feet, carrying the coal beds, begins at 600 feet from the bottom. Four beds with, in all, 20 feet of coal have been discovered and prospected. The coal throughout is in alternate bright and dull bands, the latter predominating; but the dull bands

[231] D. White, "Origin of Coal," p. 24.

[232] R. Thiessen, "Microscopic Study of Coal," p. 243.

[233] D. B. Dowling, "Coal Fields of British Columbia," Geol. Surv. of Canada, Mem. 69, 1915, pp. 263 ff., 289 ff., 298 ff., 309, 321.

include many small lenses of bright coal. The dip is from 20 to 70 degrees, usually about 40. The ash, as shown by the analyses, is rather high, the samples being prisms from the whole bed. Some of the coal gives a strong coherent coke. On Hat Creek, G. M. Dawson obtained this section: (1) Grayish and brownish shales and sandy clays, with thin layers of lignite, about 20 feet; (2) lignite with shales, shaly and lenticular layers of silicious limestone, ironstone and shale; the lignite is fairly good, forms about two thirds of the whole and contains much crumbling amber, 26 feet; (3) lignite with little impurity, compact below, softer above, 42 feet, with the bottom not reached.

The lignite of the great mass is without foreign materials aside from irregular masses of calcareous or silicious stumps. Analyses show that the quality is good, there being only 9 per cent. of ash and 8.60 of moisture.

There are several small areas along the upper portion of the Fraser River; the lignite is unimportant but G. M. Dawson has given some notes respecting the rocks. The material of the upper beds is pale greenish and grayish white, very fine-grained and often a fireclay; at times it is rich in diatoms. The beds are mostly horizontal but occasionally a local disturbance gives a dip of 20 degrees. Impressions of roots and branches are common and two silicified stumps, evidently in place, were seen. The beds turn up around the stumps and thin out toward them. The lignite, at the bottom of the section, is not in well-defined beds but is interstratified throughout with clays and appears to have been deposited as driftwood by somewhat rapidly flowing water; it is not pure enough to be of any value. Small spots and drops of amber are abundant in some layers. Little is known respecting the extent or importance of the other areas. The field geologists of Canada are in full accord with the palæontologists in the belief that these widely separated deposits were laid down in lakes or in estuaries.

The Eocene coals of Alaska have been studied more or less in detail during the last 40 years. Dall's[234] examinations were made in 1875, and the essential portions of his descriptions have been

[234] W. H. Dall, "Report on Coal and Lignite of Alaska," Seventeenth Ann. Rep. U. S. Geol. Survey, Pt. I., 1896, pp. 771–908.

republished in his report upon a reëxamination of the region in 1895. His studies were confined to the southern coast and the adjacent islands. Coal was discovered long ago on Admiralty Island, which is east from Baronoff Island, on which Sitka is situated. The first opening was made on Mitchell Bay and the coal was tested on the U.S.S. Saginaw, but the resin was so abundant as to render it unfit for use. The beds are very thin but, owing to the urgent need for fuel, they were studied carefully. The especial features are the woody structure and the abundance of resin. Kachemak Bay, near the mouth of Cook's Inlet, on the Kenai Peninsula, is 1,200 miles west from Admiralty Island. Furnhjelm, long ago, saw there a bed of coal, 9 to 11 feet thick, underlying clays, pebble rock and sands, and resting on partly bituminous laminated clay shale. It was black, brilliant and contained grains of amber. From the associated rocks he obtained *Unio, Amnicola, Melania* and elytra of a beetle, along with 44 species of plants, both conifers and dicotyledons. The bed was no longer exposed when Dall visited the locality, but, at Coal Point, he saw a bed 7 feet thick. In 1895, this bed had been opened at the Bradley mine, where it showed leaf-bearing partings and the best coal was at the bottom. Two other beds were examined on this bay, 4 feet 7 inches and 6 feet thick. These are complex. The coal differs in the several beds; that at the Bradley mine is evidently a glance, not soiling the fingers and, on drying, breaking into cubical fragments, whereas that from the Eastland mine is fibrous, dull charcoal black.

At Amalik Harbor, 150 miles farther west, some thin coal beds were seen, as also at Chignak, nearly 300 miles beyond. Amber has been obtained on the shore of Portage Bay southward from Chignak and from several other places in that region, as well as from several of the Aleutian Islands. Many thin beds of lignite were seen on Unga Island. One of these is very complex; the upper portion has half a dozen benches of bright and dull coal, each 4 to 5 inches thick, with thicker partings of carbonaceous shale. The bench is fairly clean and 18 inches thick. Analyses of coal from this bed gave

On the basis of pure coal, the volatile is 49.55 and 81.26 in the two

coals. Both are described as lignite but the composition of the lower bench, dull coal, suggests that it is of Lebertorf origin. Coal from a bed on Kachemak Bay is of the same type, as it has 71.3 per cent. of volatile.

	Water.	Volatile.	Fixed Carbon.	Ash.
Upper part	11.26	40.51	41.24	6.99
Lower part	10.58	66.21	15.26	7.95

Eldridge,[235] during examination of a district in eastern Alaska, discovered 10 to 15 deposits of low-grade lignite, 6 inches to 6 feet thick. The material resembles a mass of compressed carbonized wood. Stumps, one to two feet in diameter, are common and stand erect. These, by their appearance and by their association with abundance of slivers and other carbonized material, suggest that the coal beds originated in swamp vegetation. Occasionally, the coal shows no woody structure and resembles the higher grades of lignite, which shade off into bituminous coal.

Collier, not long afterwards, examined beds along the upper Yukon River, where the coal is either lignite or lignitic, little disturbed and usually contains amber. He visited a locality in the province of Yukon, Canada, 20 miles from Dawson and 7 from the Klondike, where R. G. McConnell had seen a double bed with 5 to 6 feet of coal, hard, without woody fiber and of practically the same composition in both benches. At 20 miles below Dawson, he saw 3 beds mined, all with one or more partings and all showing abundance of resin. At Washington Creek, 80 miles below the international boundary, he found a bed measuring clean coal, with thin partings, 5 feet 6 inches; dirty coal, 2 feet 6 inches; sandstone, 2 feet; shale, 2 inches; coal, 2 feet. The dip is 45 degrees, but there is neither crushing nor faulting. The coal is black, glossy and has conchoidal fracture, but it often shows woody structure and it contains streaks as well as grains of resin. The coal beds, seen by Col-

[235] G. H. Eldridge, "Reconnaissance of the Sushitna and Adjacent Territory, Alaska," Twentieth Ann. Rep. U. S. Geol. Survey, 1900, Pt. VII., pp. 21–23.

lier[236] at numerous localities farther down the Yukon, show the same general features as those already referred to.

Martin and Katz[237] found in the Matanuska region beds of dark fissile shale with bands of ironstone. The coal beds, in some cases, are thick and commercially good, but in others they consist merely of thin alternating layers of coal and shale, so that, though the coal predominates, the thick mass is worthless. The upper half of the section, about 1,000 feet, is composed chiefly of dark shales with thin beds of sandstone and many thicker beds of carbonaceous shale, which are leaf-bearing and include petty lenses of coal. The authors saw several fossil logs and tree stumps in an exposure, where one of them is 20 feet long and vertical to the bedding. Petrified fragments of wood appear to be not rare.

Henshaw[238] has given a brief note respecting the great bed on Chicago Creek, in Seward Peninsula and almost directly under the Arctic circle. The dip is 18 to 36 degrees and the thickness is 88 feet. The coal is frozen as in Spitzbergen and the modest mining operations are prosecuted during the short summer. The tunnel had been cleaned out only a short time before Henshaw's visit and he was able to make examination of the whole bed. It is an almost continuous mass of coal, broken only by a few layers of bony coal and sandy shale. Atwood[239] notes that in the Cook Inlet area, the coal beds are many, varying from mere films to 20 feet. At a mine near Tyonek, the coal is a tough, woody lignite and contains large trunks of trees, which are only partly converted. The mode of their occurrence suggests to him that they may be logs drifted into a pond or swamp, or that they are a group of fallen forest trees.

Tertiary coals have been observed at many localities in Siberia, but available notes respecting them are few and the age of the coals seems to be somewhat uncertain. The summary description of

[236] A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 17, 19, 22–26, 30–39.

[237] G. C. Martin and F. J. Katz, "Lower Matanuska Valley," U. S. Geol. Survey, Bull. 500, 1912, pp. 44–48.

[238] F. F. Henshaw, "Mining in the Fairhaven Precinct," U. S. Geol. Survey, Bull. 379, 1909, pp. 362.

[239] W. W. Atwood, "Mineral Resources of Southwestern Alaska," the same, p. 117.

Siberian resources[240] states that south-southwest from the Irtych River a thin bed of lignite was seen, which retains the woody texture and contains grains of amber. Lignite-bearing Tertiaries are of notable extent in the Transbaikal region; they are later in origin than the present topography of the country; the rocks show leaf impressions and contain silicified stems of dicotyledonous trees. The lignite beds are 2 to 4 meters thick but are lens-like, thinning away at the borders.

Some Chemical Features of the Tertiary Coals.—The literature dealing with the chemistry of Tertiary coals is voluminous, but comparatively little of it is serviceable for the present study. Analyses, for the most part, are of coal from localities where the fuel values had been proved long before the analyses were made: comparatively few are from deposits which are not important economically. In the United States and Canada, the samples are prisms from the whole face of a bed, only such partings being removed as should be separated from the coal before shipment. Analyses of such samples afford no clue to the varying conditions during accumulation of a bed. It is well understood that a proximate analysis of coal containing a high percentage of water yields at best only tentative results, varying in any case with the temperature employed. Ultimate analyses are, from the geologist's standpoint, little better, since coals of wholly different types may have practically the same ultimate composition, as was shown by Carnot. Coals are apparently mixtures of various hydrocarbons, respecting which very little is known, as only a few of them are acted on by solvents. But one must make use of the material within reach and much can be learned by comparison of analyses made after the same method; the official laboratories in the United States afford abundant material.

In studying the mature deposits of peat, known as Schieferkohle, v. Gümbel discovered a dopplerite-like material, which had saturated the mass and had become insoluble. A similar substance is in brown coal. Glöckner[241] examined the black lustrous coal, with conchoidal

[240] Le Comité Géologique de Russie, "Aperçu des Explorations géologiques et minières le long du Transsibirien," St. Peterbourg, 1900, pp. 42, 68, 87, 123, 153.

[241] Fr. Glöckner, "Ueber Zittavit, ein epigenetische, dopplerit-ähnliches Braunkohlengestein," *Zeitsch. d. d. geol. Gesell.*, 1911, pp. 418, 419.

fracture, which he saw in the brown coal of Zittau in Saxony. Siegert and Hermance had thought it identical with Pechkohle or Glanzkohle, but Glöckner objects to both terms as not specific, bcause they have been employed loosely in description of both brown and stone coals. He regards dopplerite as almost equally bad, because there is no agreement respecting it, except as to the fact that it is formed in recent peat moors. He prefers a new name for this tertiary substance, which is distinguished from dopplerite by its brittleness and its hardness, 2.5. Analysis of this zittavite, dried at 105° C., yielded carbon, 61.89, hydrogen, 5.32, oxygen, 30.43, nitrogen, 0.21, ash, 1.95. Comparing these results with those obtained by Demel, Kaufmann and Schrötter for dopplerite, one finds that Glöckner's material is more advanced than that studied by those chemists. They obtained for air-dried, ash-free dopplerite

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Demel	56.42	5.80	37.20
Kaufmann	55.94	5.20	38.86
Schrötter	51.69	5.34	43.03

One can hardly regard zittavite as a good mineral for, like dopplerite, it varies in composition and there would seem to be little reason for giving it a new name, except to distinguish the geological position. Glöckner recognizes similarity in origin, for zittavite is due to humic solutions formed during change of woody material into lignite and earthy brown coal, which circulate through the mass. He cannot believe that it results from action of calcium carbonate, because limy matter is but 0.47 per cent. of the whole. The characteristics suggest very close relationship to the carbohumin of v. Gümbel. D. White has expressed frequently the conviction that the conversion of wood into jet-like lignite is due to saturation by soluble compounds generated during decomposition of vegetable matter.

With comparatively few exceptions, students of the Tertiary coals have noted the presence in greater or less quantity of resins in streaks, nests or isolated globules, especially in coals of lignitic and sub-bituminous types, even occasionally in those closely allied to

the bituminous grade. The scanty notices of Pliocene coals contain few references to resins, the only definite note being that by Hutton respecting New Zealand, in which he states that the coal often contains large lumps of retinite. Thiessen found much resin in the Miocene coal of Monte Diablo of California; Brown and Potonié note the considerable proportion of resins in the coals of Greenland and southern Prussia. The Oligocene coals of Germany and British Columbia are rich in resin and, at times, it is found in cavities within fossil wood. Eocene coals throughout, when they are lignite or subbituminous, are notably resinous, material of that type occasionally composes a great part of the mass. The term retinite is employed frequently as a group name, but the resins are many. Amber or Bernstein, the best known popularly, has been reported from numerous places, widely separated. Dall states that it has been obtained at many points in Alaska; Daubrée observed it in the Bas-Rhin province and Potonié says that it is abundant at Senftenberg. But this mineral occurs in commercial quantity chiefly on the Baltic coast of Prussia, where, according to Karsten,[242] it is procured by digging and by dredging. In the former process, the recent sands are removed and the underlying clay shales, known as "amber veins," are exposed, in which are nests of brown coal and amber, apparently much compressed. These overlie coarse greenish sand, under which the important deposit is reached. This, with the overlying sand, extends under the sea and is the source of the amber, which is thrown on shore by the waves or is obtained by dredging.

Potonié[243] states that Bernstein occurs over the whole of North Germany, Poland, Russian Baltic provinces and Finland as well as in many other regions; but it is most abundant in Sammland, near Königsberg. There it occurs at three horizons. The original deposit is now below the sea, whence it is washed up by the waves; but these Eocene beds were gashed by glaciers and now the mineral is found also in glacial drift. The Bernstein forest grew on Cretaceous débris. This fossil resin, originally fluid, is an exudation

[242] H. Karsten, "Ueber das Vorkommen des Bernsteins an der preussische Küste," *Karsten's Archives,* Vol. 2, 1830, pp. 289, 290.

[243] H. Potonié, "Der baltische Bernsteins," *Natur-Wochensch.,* Bd. VI., 1891, pp. 21–25.

from a conifer, which Conwentz has named *Pinus succinifera*. The resiniferous organs were mostly in the bark and twigs but were abundant even in the wood itself. The conditions in these old forests were very similar to those observed in conifer forests of Bohemia: there could have been hardly any sound trees in the old Bernstein forests; wind, weather, saprophytes and other plant parasites, insects and other animals caused injury and led to flow of the resin. Bernstein is complex, consisting of gedanite, soft, yellow, transparent and fusing at about 180° C.; glissite, brown, opaque; stantienite, black, tender, brittle; bechanite, brown, tender, brittle; succinite, transparent, lustrous, yellow, brittle, fusing at 250–300° C.

The resemblance of these resins to some of recent age is very great and the origin is similar. They are exudations from coniferous trees and are resistant to decomposing agents, so that the proportion becomes greater as the process of decomposition advances in the vegetable material. Amber is associated, at times, with fragments of the trees whence it was derived, but in many places, as is the case with the recent kauri and copal, the woody materials have disappeared, leaving the resin free in the sands.

Pyropissite is locally characteristic of Oligocene coals in much of the Sachsen area of southern Prussia, where it, as well as Schwelkohle, a mixture of pyropissite and fuel coal, is distilled for the paraffins; it occurs also in the Miocene and Eocene of other regions. Karsten,[244] in a brief communication to the German Geological Society, described it as a peculiar earthy brown coal, which forms the roof of a bed near Weissenfels as well as of one near Helbra, between Mansfeld and Eisleben. It passes gradually into the ordinary brown coal, has gravity of 0.9 and leaves 13.5 per cent. of ash. At from 100° to 125° C., it gives off a heavy white vapor and at red heat the product is an oily liquid. Stirred in an open vessel, the whole mass liquefies and becomes pitch-like; in burning it gives off a disagreeable odor. The composition, ash and water free, is carbon, 68.92, hydrogen, 10.30, oxygen, 20.78, while that of the associated brown coal is carbon, 64.32, hydrogen, 5.63 [oxygen and nitrogen, 30.05]. The last two constituents are not given by Karsten.

[244] Karsten, *Zeitsch. d. d. geol. Gesell.*, Bd. II., 1850, p. 71.

Schwelkohle was formerly cast aside as worthless, but it has been utilized in the paraffin industry during later years as the supply of pyropissite is practically exhausted. As shown by Raefler the coal is richest in pyropissite on the borders of several petty basins, the proportion decreasing toward the middle. In the larger basin near Zeitz in Sachsen, the proportion of pyropissite becomes negligible as one goes eastward, but it increases again farther east, beyond the central line of the basin. The origin of the material is obscure. Potonié, in describing the Senftenberg coal, says that many of the stumps, *Taxodium distichum,* are hollow and those at the bottom contain Schwelkohle in the cavity. But the Schwelkohle in hollow stumps is not confined to the bottom of the deposit though it is more abundant there. He thinks that this substance was produced by flow of resin, which must have been great in the wounded trees; but one has difficulty in conceiving how a stump, which had been dead long enough to become hollow, could still retain enough vitality to pour out a great quantity of resin for healing of its wounds. Whether or not it is a resin may be open to discussion. The microscopic study of the Weissenfels pyropissite by v. Gümbel led to no definite results but in the Sauforst material he found a great quantity of exines of pollen. The mode of its occurrence seems to suggest that it is not unrelated to the Lebertorfs in origin. Potonié regards it as resinous and its occurrence as layers or smuts in what he recognizes as autochthonous coal is explained by the suggestion, that these may mark dry places, where the exposed coal was removed by decomposition and the resin was left unmingled with foreign matter.

It appears wholly probable that pyropissite was an original constituent, not a product of chemical action during conversion of the vegetable material. Kraemer and Spilker thought it formed by green algæ while Witt believed that it was derived from spores. Graefe, considering the contrast between pyropissite and the undoubted resin, retinite, cannot regard a resin as the source of pyropissite, and concludes that wax-like secretions of plants were in chief part the original material. Treated with benzol, pyropissite yielded 69.5 per cent. of "bitumen," while good Schwelkohle yielded 27.3 per cent.—the calculation in each case being for the dry substance. Raefler

says that the poorer the coal is in benzol extract, the richer it is in resin. "Bitumen" from pyropissite contains no resin soluble in ether, but that from bitumen-poor coal may contain 25 per cent.

Bredlick[245] states that Schwelkohle, when dried, resembles an earthy brown coal soaked in a wax-like bitumen. It is not homogeneous but consists of layers of richly bituminous lignite. It fuses at 150° to 200° C., thereby differing from fuel coal, which is infusible. He cites Riebeck on composition of pyropissite, which, ash-free, is carbon, 73.48, hydrogen, 11.70, oxygen, 14.80, while the associated fuel coal, according to Bredlick's analysis, has carbon, 64.78, hydrogen, 5.65, oxygen and nitrogen, 29.56. The several substances, when subjected to destructive distillation, yield

	Tar.	Water.	Coke.	Gas and Loss.
Pyropissite	64.2	7.7	16.3	11.8
Distillation coal	33.0	23.0	35.0	9.0
Fuel coal	5.0	63.5	25.0	6.5

Gas begins to pass off from pyropissite at 120° C. to 150° C., and the maximum temperature reached in the process is 640° C. The tar is of butterlike consistence when cooled, has gravity of 0.85 to 0.91, consists chiefly of paraffins and olefins, there being only traces of benzol and its homologues. This tar is fractioned and yields a paraffin free oil and paraffin wax, with a residuum. The last, about one third of the whole, is placed in another retort and heated to beyond the "cracking point." The gas from Schwelkohle is inferior; according to Graefe, its composition is: Carbon dioxide, 10.9; heavy hydrocarbons, 1.1; oxygen, 6.3; carbon monoxide, 8.5; hydrogen, 22.6; carburetted hydrogen, 6.4; ethane, 2.0; nitrogen, 42.2. The candle-power is from 8 to 12.

The Blätterkohle or Dysodil, which is a Tertiary Lebertorf, has been found in Sicily, France, Bohemia and other countries, but the most important deposits are near the Rhine in the Siebengebirge. The composition of material from Westerburg, according to Casselmann,[246] is: Carbon, 62.80; hydrogen, 6.76; oxygen and nitrogen,

[245] W. Bredlick in "Fuels Used in Texas," Bull. Univ. Texas, 307, 1913, pp. 169–178.

[246] Cited by C. F. Zincken, p. 180.

19.43; ash, 11.00. This coal, which is utilized, like Schwelkohle, for production of oils and paraffin, yields, according to H. Vohl,[247] by distillation: Water, 24.214; tar, 20.014; coaly residue, 46.326; gas, 9.446. The Blätterkohle of Rott yields 15 to 20 per cent. of tar on the large scale. This tar, when fractioned, gives: Photogen, 16; solarol, 24; paraffin, 20; hard paraffin, 4, from 100 pounds of tar.

Cannel-like coal has been reported from Washington, Alaska and Arkansas. That from Lewis county of Washington is extremely high in volatile, but no analysis is available. Analyses of two coals from Alaska show 71.3 and 81.26 of volatile. The Lester coal of Arkansas has 68.06 per cent., in the pure coal, and the best quality is said to yield 38 gallons of oil per ton. Lenses of cannel-like coal occur at Hoyt in Texas, but no analysis has been made. "Oil shale" of high grade has been found in New Zealand.

Analyses of brown coal, both proximate and ultimate, seem to be abundant enough for all purposes. Those from European localities are almost all from mines which have been long in operation and which yield coal proved to be marketable. In much of the areas within the United States, the coal has been mined in a small way to supply the owner's needs or those of a very small population; samples have been taken from these as well as from mines of great capacity, so that the reports from Government laboratories tell much respecting the variations in character. In almost every instance, the samples are prisms from the whole face of the bed, so that there is little information as to varying conditions during accumulation of the beds.

Comparatively few analyses of Pliocene coals have been reported. Hutton has given four for the Otago, New Zealand, basins and Hantken has given six for those of Hungary; reduced to pure coal basis, these are

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Volatile	51.6	71.1	56.3	53.3	20.1	22.2	23.7	25.0	27.4	46.0
Fixed carbon	48.3	28.8	43.6	46.6	79.9	77.7	76.2	74.9	72.6	53.9

Hutton's specimens were air-dried and contained from 11 to 16 per

[247] Cited by Heusler, p. 133.

cent. of water. The ash is from 2.80 to 29.58. The samples were evidently selected specimens and Hutton seems to think that the selection was not always judicious. The water in Hantken's samples varies from 17.57 to 27.2 and the ash is low, barely 5 per cent., except in No. IX., where it is almost 20 per cent. of the dried material. No relation appears here between the quantity of ash and that of volatile matter.[248]

Von Ammon[249] published several ultimate analyses from mines in Bavaria;

	I.	II.	III.	IV.	V.
Carbon......	68.64	69.42	62.76	69.70	65.90
Hydrogen ...	6.56	6.38	4.91	5.70	5.32
Oxygen	24.79	24.20	32.29	24.90	28.68

No. I. is a briquette with 10 per cent. of water and 13.21 of ash; No. II. is a fresh specimen from the Oettingen locality and contains 63 per cent. of water; No. 3 is lignit, bituminous wood, from Schwarzenfeld and No. IV. from the same place is woody; these have 41 and 36 per cent. of water but the ash is only 2.28; No. V. is a strongly dried brown coal, which has 24 per cent. of water and 9 of ash.

The number of analyses is small but they represent the best coals in the petty areas whence the samples were taken. Compared with peats, the proximate analyses show notable decrease in volatile, so great indeed in the Hungarian coals as to suggest the possibility of some metamorphic action. The ultimate analyses from Bavaria show an advance beyond mature peat in the carbon but it is not constant, for No. III. is poorer in carbon and richer in oxygen than some peats.

Miocene Coals.—Arnold has published two analyses from the Monte Diablo field in California, one representing a 5-feet cut at the top and the other, the lower part of the bed; Pardee has given two of the coal in southwestern Montana. These, made by the Bureau of Mines, show:

[248] F. W. Hutton, "Geology of Otago," p. 97; M. Hantken, op. cit., p. 341.
[249] L. v. Ammon, op. cit., pp. 18, 27.

	Volatile.	Fixed Carbon.	Sulphur.	C.	H.	O.	N.	Water.
I..........	54.57	45.43	5.64					
II.........	53.78	46.22	4.80	79.87	6.66	12.05	1.42	7.13
III........	52.90	47.10	1.53	70.42	5.08	21.64	1.33	6.93
IV........	59.20	40.80	2.15	72.20	6.73	17.93	0.99	10.00

The dips in the Monte Diablo area reach 70 degrees; the water in the coal is always low, sometimes not more than 3 per cent.; the ash is from 4 to 18 per cent.; but everywhere the coal seems to be very far from the bituminous grade. In southeastern Montana, the ash varies from 15 to 25 per cent.

The air-dried samples of Greenland coal, analyzed by Moss, as already cited, resemble a good bituminous coal, but the coal is a typical brown coal in all physical features. Miocene coals from Trinidad were analyzed by Percy, who obtained

	C.	H.	O and N.	Water.	Ash.
I...........	72.98	4.75	22.95	16.80	3.90
II..........	72.20	5.40	22.40	17.65	2.40
III..........	80.11	5.51	14.35	20.50	2.10
IV..........	77.16	5.83	16.89	5.90	3.44

In every case, the specimen for analysis was taken from the outcrop; all are attacked energetically by caustic potash. Experiments in the Survey laboratory showed that No. IV cakes. Resins appear to be wanting.[250]

A. S. McCreath's analyses of coal from the Miocene of Advent Bay, Spitzbergen, gave for different parts of the bed

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper part ..	3.310	19.790	62.763	0.467	13.670
Lower part ..	4.696	28.560	57.171	0.413	9.160

N. Dubois determined the ultimate composition of slack coal from the lower part of the bed, thus: Water, 4.14; carbon, 67.88; hydrogen, 4.05; oxygen and nitrogen, 11.90; ash, 12.03, or about 83 per cent. of carbon and 14 of oxygen in the pure coal. The notable features

[250] G. P. Wall and J. G. Sawkins, "Trinidad," etc., pp. 123, 126.

are the low water throughout and the great difference in volatile of the two parts of the bed, more than 9 per cent. in the pure coal. This coal is very similar in appearance to many Carboniferous coals but it is attacked by caustic potash to an unusual degree.[251]

Von Ammon[252] reports analyses from the small Miocene area in Bavaria, which exhibit much variability in composition.

	C.	H.	O and N.
I	49.01	5.15	45.82
II	70.93	4.25	24.81
III	60.43	4.47	35.08

The ash varies from 3 to 28 per cent. and the sulphur from 0.40 to 8 per cent. The first and third are very similar to peat in composition; the second is a Pechkohle from Schwarzen Moor.

The Grottauer coal of Bohemia contains, according to Katzer, 50 per cent. of water when freshly mined; dried at 110° C., it has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.97. The sulphur, as pyrite and in organic combination, sometimes reaches 3.84 per cent.

The Hungarian coals show considerable variation in composition. Nendtvich[253] gives analyses from two beds thus:

	Water.	Volatile.	C.	H.	O and N.
Rudolphilager	18.68	49.11	70.849	4.715	24.445
	17.00	44.02	72.185	5.185	22.630
Josephilager	17.82	67.00	72.490	5.175	22.235
	17.10	54.00	71.360	5.095	23.545

These are from near Oedenburg; having been made according to the same method, they are comparable. They make clear that for comparisons one needs both ultimate and proximate analyses. The second from Rudolphi and the first from Josephi have almost the same ultimate composition, yet the latter yields about 23 per cent. more volatile than the former, showing that it has very different constituents. The analyses for each are from different portions of

[251] In *Annals N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 86, 87.

[252] L. v. Ammon, op. cit., pp. 62, 64.

[253] C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 40–44.

the bed. The ash varies from about 2 to 5 per cent. Hantken[254] gives three analyses, which are equally illustrative; one is of coal from Édéleny and the other two from near Brennberg.

	C.	H.	O.
I	53.85	4.21	41.94
II	71.92	4.95	23.53
III	71.90	5.14	22.89

These are all used as fuel; at Édéleny, the ash varies from 15 to 21 per cent. and the water from 21 to 61 per cent., so that the fuel is of decidedly poor quality; but at Brennberg, the water does not exceed 18 per cent. and the highest ash is 3.45. These Miocene deposits are confined to very small areas.

Oligocene Coals.—These are of great importance in Prussia and in Hungary. Hantken[255] has given proximate analyses of coals from the Zsil valley and from two parts of one mine near Gran:

	Water.	Fixed Carbon.	Ash.	Volatile.
I	4.83	58.50	6.55	36.67
II	14.09	59.53	3.55	22.53
III	12.727	38.035	8.217	40.921

Ultimate analyses from two localities in the Gran area, including the mine already referred to, have been given by Hantken and four others were published by Nendtvich:

	C.	H.	O and N.	Volatile in Pure Coal.
I. Szt. Ivan	64.92	4.94	30.10	
II. Gran	69.30	4.80	27.00	27.45
III. Gran	68.58	4.67	26.75	51.82
IV. Tokodt	67.495	4.70	27.80	31.30
V. Sarisap	67.85	4.83	27.22	38.77
VI. Csolnok	71.55	5.19	23.25	47.44
VII. Zsemli	71.89	4.79	23.31	40.45

The two coals from different parts of the mine at Gran have practically the same ultimate composition, yet in the pure coal there is a difference of 23 per cent. in the volatile. The contrasts are not

[254] M. Hantken, op. cit., pp. 315–325.

[255] M. Hantken, pp. 247, 259, 260, 262, 280, 286, 289; C. M. Nendtvich, p. 32.

so great in the coals analyzed by Nendtvich, but there is a difference of 7 per cent. in the volatile of two coals with essentially the same ultimate composition. The water in these Hungarian coals is from 4.83 to 17 per cent. and the ash from 4.23 to 11 per cent.

The coals of Brandenburg, in the region studied by Plettner, show notable variation, according to analyses reported by Zincken;

	C.	H.	O and N.
Perleberg, Erdkohle	66.32	5.20	28.48
Frankfurt a. O., Knorpel	65.60	5.36	29.04
Neudorf, Formkohle	60.00	6.56	33.44
Fürstenwalde, Formkohle	70.64	5.22	24.14
Knorpelkohle	68.37	5.47	26.16

A great part of the Sachsen coal is Formkohle, which according to analyses by Karsten and Bredlick, cited on an earlier page, contains from 62.74 to 64.32 of carbon and the oxygen varies little from 30 per cent. The analyses of the Brandenburg coals seem to indicate that the composition and the physical structure of the coal are not related, Formkohle being highest and lowest in carbon as well as in oxygen. These Oligocene coals differ not much from mature peat in their composition.[256]

Katzer analyzed two samples from an opening in the Lãuser bench of the bed near Banjaluka in Bosnia, which show no great variation;

	C.	H.	O and N.
I	74.51	5.08	20.41
II	71.83	4.96	23.11

The water is from 21.82 to 29.05 and the ash, 7.40 to 8.45; sulphur is high, from 6 to 7 per cent.

The Oligocene coals of British Columbia are, in many cases, bituminous; the region being more or less affected by eruptive rock. It is not certain that the analyses reported give any clear conception respecting the general character of the coal, as the samples analyzed were selected from the outcrops.

[256] C. Zincken, pp. 28, 29.

Eocene Coals.—The analyses of Southland coals in New Zealand, reported by Hutton, are all proximate; they show the volatile varying from 39 to 63.74 in the pure coal, while the water is from about 15 to 17 and the ash from 2.80 to 12.45 per cent. The samples appear to have been selected and not to be representative of the whole bed. No relation appears here between the proportion of ash and that of volatile. Zincken has given an analysis of the English Bovey Tracey coal, apparently by himself, and Dana[257] has published an analysis by Vaux. Ash and sulphur free, these are

	C.	H.	O and N.
I	69.95	5.93	24.11
II	69.52	5.90	24.56

The Eocene coals of Texas are mined extensively at many localities and Phillips and Worrell[258] have made numerous analyses, the samples having been collected in all cases in accordance with the official method. The composition of these coals varies greatly, even in a single bed within a limited area. The conditions are clear from comparisons of the samples taken from several mines near Rockdale in Milam county. All are reduced to pure coal basis except for water and ash, which are for the coal as received:

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
1538	32.79	10.70	61.8	38.1	69.71	5.54	24.74
1539	34.72	11.76	60.8	39.1	73.63	5.48	20.87
1540	32.27	12.05	74.3	25.5	67.36	4.99	21.64
1541	33.63	18.27	86.2	13.7	72.84	5.07	22.08
1542	31.52	9.45	71.7	28.2	67.38	5.50	27.11
1543	29.07	26.47	54.2	45.7	77.11	5.46	17.41

The samples are all from the same bed and are in close proximity; it is clear that no relation exists between ash and volatile matter. It is equally clear that the conditions were not the same throughout the basin during accumulation of the peat. This appears from the

[257] C. Zincken, p. 28; J. D. Dana, "Manual of Geology," 1895, p. 662.

[258] W. B. Phillips and S. H. Worrell, "The Fuels Used in Texas," pp. 85–89, 91, 92, 98, 100.

variation in percentage of the ash; but it is more apparent when one considers the composition of the ash in the several samples:

	Silica.	Alumina.	Ferric Ox.	Calc. Ox.	Magnes. Ox.	Sulphuric Acid.
1538.....	21.64	16.20	11.10	25.23	4.36	18.01
1539.....	33.06	16.77	8.47	23.00	1.28	17.10
1540.....	27.44	28.87	24.85	7.00	0.00	10.45
1541.....	23.20	11.94	5.08	38.17	1.00	7.79
1542.....	42.20	23.02	2.02	15.93	2.12	12.81
1543.....	47.04	23.18	18.32	6.64	0.00	4.58

In these coals one has another illustration of indefiniteness of analyses as indications of the actual composition of coal. Nos. 1539 and 1541 have almost the same ultimate composition, yet there is a difference of more than 25 per cent. in the volatile.

Analyses of coals in the Wyoming-Montana-North Dakota region are numerous. Taff and Wegemann cut samples in the Sheridan and Barber fields. Ten beds were sampled in a vertical section of about 1,900 feet. The variations in composition are less than those found within a single bed in the Rockdale area of Texas. The volatile in the lowest bed is 46.30 and that in the highest is 47.67; but in one midway in the section it is 44.69, and in the one next above it is 53.20, while in the next to the highest it is only 43.97. The carbon varies from 74.37 in the lowest bed to 70.97 in the highest, but in a bed almost midway in the section it is 71.96. The oxygen is 20.42 in the lowest bed and 22.95 in the highest, but is lowest in an intervening bed. The coal throughout this region appears to be remarkably free from inorganic matter, as the ash varies from 4.10 to 9.95 per cent. of the dry coal and it is usually less than 7 per cent.[259]

Somewhat farther north, in the Red Lodge field of eastern Montana, samples were cut by Woodruff and were analyzed at the same laboratory. Eight analyses were made of six beds exposed in a section of approximately 475 feet. The volatile is from 37.35 in the lowest bed to 45.85 in the highest; but in another analysis, the lowest bed shows 43.35 and the fifth bed, ascending, has but 42.66. The carbon is 72.66 in the lowest and 74.41 in the fifth bed, while in the

[259] U. S. Bureau of Mines, Bull. 22, 1913, pp. 307–309.

same beds the oxygen is 20.77 and 16.94 in the two analyses of the bottom bed while it is but 17.85 in the fifth. The ash is from 6.02 to 13.31 per cent. of the freshly mined coal, which contains 8.60 to 11.69 of water. Much of the coal, according to these analyses, would be regarded as inferior. In this field, as in the Sheridan, there is no relation between ash and volatile and comparison of analyses shows that position in the section is not very important. Proximate analyses from the Miles City field in Montana tell the same story, for the volatile varies from 42.49 to 49.60 in sound coal from the lowest bed, while a single analysis of crop coal from a bed, 800 feet higher, shows 48.09. Water in the lowest bed is from 29.25 to 43.70, while that of the highest is 35.51.[260]

Analyses were made of 7 samples cut in the Snyder mine near Glendive on the eastern border of Montana.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
2423	39.94	5.61	45.40	54.60			
3812	34.55	7.20	60.67	39.33	72.79	4.74	20.58
3815	33.65	6.90	49.84	50.16	67.87	3.97	26.80
3816	34.89	8.07	76.23	23.77	73.04	4.43	20.20
3817	31.26	6.80	68.49	31.51	70.92	4.07	23.72
3819	33.06	8.33	51.70	48.30			
3820	33.06	6.26	65.62	34.38			

Ultimate analysis was made of only four samples. In all cases, sampled by the official method, the coal is sealed in waterproof cans at once, so that it reaches the laboratory in fresh condition.

The ash varies in this small mine from 8.62 to 12.44 per cent. of the dried material; no relation exists between it and the volatile; 3816 and 3819 have practically the same ash, 12.39 and 12.44, but there is almost 25 per cent. difference in the volatile. 3815 and 3816 have almost the same ultimate composition, but their volatile differs by almost 16 per cent.

The Leonard and Smith samples are from eastern North Dakota, and their bed *C* is taken to be about 300 feet above the Glendive bed; bed *G* is somewhat more than 250 feet above *C*.

[260] The same, Bull. 22, pp. 124–126.

	Water.	Ash.	Volatile.	Fixed Carbon.
2428 *C*	38.45	5.69	50.16	49.84
5779 *E*	34.50	7.51	51.05	48.95
5782 *E*	35.72	8.86	57.53	42.47
5782 *F*	35.40	5.64	64.86	35.14
5784 *F*	43.51	6.39	50.37	49.63
2427 *G*	29.78	6.56	50.74	49.26

No ultimate analyses of these samples were made, but the proximate analyses suffice to show the great variability in conditions under which the coals accumulated; there is notable difference in ash; in the two analyses of coal bed *F* one finds a difference of more than 14 per cent. of volatile.

The coals of the state of Washington have great economic importance and a great mass of analyses is available. In that state one finds all grades of coal from peat-like material to graphitic anthracite within the Eocene column; at many localities the coals yield coke of excellent quality. One may select only a few of the analyses as illustrating the variations. In King county the water is low, rarely exceeding 12, usually below 9 and in a great number of cases is below 6 per cent. in the freshly mined coal. The ash is high, not often below 12 and very frequently above 20 per cent. in the dry coal. The first five analyses, which follow, are from the several beds near Issaquah and are of subbituminous coal; the sixth is bituminous and the seventh is of coking coal from Bayne.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
8544 I	14.2	13.59	40.9	59.1	76.51	5.66	17.34
8445 II............	13.8	20.53	47.3	52.7	74.77	6.00	18.51
11736 III...........	15.9	11.4	48.4	51.6			
11737 IV...........	16.5	24.4	52.4	47.6			
8543 V............	15.1	13.36	39.9	60.1	75.52	5.41	17.55
9114..............	4.9	4.74	46.2	53.8	79.96	5.86	13.67
9485..............	4.2	11.62	38.3	61.7	81.52	5.65	12.30

At Ronald in Kittitas county, a coking coal is found with composition differing very slightly from that of the coal at Bayne. In Pierce county, coking coals are mined at many places with 3 to 5 per cent. of water in the fresh coal; the ash is rather high in some of them,

reaching even to 16 per cent. of the dried coal; not a few of these coals have 84 to 87 per cent. of carbon. But not all of the beds yield caking coal, even where its composition is closely similar to that of the others.

The coals of Lewis county show extremes of variation, for there one finds anthracite with 6.8 of volatile and 93.2 per cent. of fixed carbon in the pure coal, whereas at Mendota the coal is lignite with 20 per cent. of water and 73 per cent. of carbon. At Ladd the coals are bituminous and that from No. 2 is coking. It has 4.1 of water and 84.62 of carbon. It yields 34.2 per cent. of volatile from the pure coal. The other beds mined on this property have only 6 to 8 per cent. of water but the volatile is much higher, 43 to 48 per cent., and they are not caking. The ash throughout is high, 18 to 26 per cent. of the dry coal.[261]

Igneous rocks are reported as cutting the coal bearing rocks at a few localities in King and Pierce counties, but for the most part the variation in the coals is regional and apparently is not due to local causes.

The Alaskan coals show all types from lignite to anthracite. The anthracite coals are in the Bering River region where the carbon content at times reaches 90 per cent.; but in the same region are bituminous and semi-bituminous coals. The lignitic type, however, prevails in the greater part of the territory.

	C.	H.	O and N.	Volatile.
I	67.45	5.27	26.63	64.44
II	69.08	5.28	25.16	50.86
III	68.77	5.02	25.93	50.53
IV	68.47	5.53	25.37	55.15
V	69.57	5.04	24.66	54.41
VI	64.60	5.44	29.55	59.16
VII	69.89	5.07	23.56	45.84
VIII	64.43	5.39	29.73	58.93
IX	69.59	5.19	24.78	53.55
X	67.40	5.47	24.71	56.97

At Coal Harbor, Unga of Dall's descriptions, in western Alaska, the analyses give for the coal, ash and water free: Carbon, 68.76; hydrogen, 5.30; oxygen and nitrogen, 24.89; volatile, 50.29.

[261] E. E. Smith, U. S. Geol. Survey, Bull. 474, 1911, pp. 42, 43, 48, 51, 64, 65, 66, 67.

On the borders of Kachemak Bay, farther east, ten samples were collected which have the composition shown in the preceding table, calculated after the same method:

Number VII. gives the composition of pebbles of lignite forming part of a conglomerate at the bottom of the Kenai (Eocene) in this district.

Nine samples were cut from the bed on Chicago Creek in the Seward Peninsula, which is 88 feet thick. In each case the sample represents a 12-fect cut. The results of analysis are:

	C.	H.	O and N.	Volatile.
I............	71.69	5.01	22.18	44.84
II...........	71.25	4.85	23.02	45.89
III..........	70.78	5.05	22.96	44.96
IV..........	70.41	4.72	23.62	43.98
V...........	74.82	4.71	19.43	43.83
VI..........	69.33	4.61	24.41	44.70
VII..........	67.32	4.85	25.90	46.73
VIII.........	68.56	5.01	23.77	46.25
IX..........	68.68	4.83	24.46	46.51

In the Kachemak area the moisture in freshly mined coal varies from 17.44 to 28 per cent. and the ash is from 10.50 to 20.34 per. cent. of the coal, dried at 105° C. But in one sample it is only 7.81. In the Chicago Creek bed the moisture is from 32 to 42 per cent. of the fresh coal and the ash is from 5.77 to 6.49 in dried coal from the upper half of the bed, as represented in analyses I. to IV., but in the remaining analyses it increases, becoming 9, 11, 31, 21 and 26 per cent., fractions being omitted.

The Kachemak analyses show that the carbon content varies from 64.60 to 69.59, but the volatile is from 50.86 to 64.44. Coals with almost exactly the same ultimate composition differ about 5 per cent. in the volatile. The Seward analyses prove great uniformity in composition of pure coal throughout the immense bed, the variation in carbon being only from 68 to 71, except in one cut, midway, where the maximum of 74 per cent. is reached. The volatile is greatest in the lowest third, where the ash is greatest; but there is no relation between the ash and the volatile; for in IX. the ash is 26.15 per cent. of the dry coal and the volatile is 46.51, while in VII. the ash

is 31.70 and the volatile is 46.73; in II. the ash is 5.77 and the volatile is 45.89.

Summary.—It is now in place to gather the facts presented and, if possible, to ascertain how far they may be related to the problem in hand.

The testimony throughout shows that Tertiary coal beds are notably limited in extent, their area varying from a few square rods to several hundreds of square miles—in some cases apparently even to 2,000 square miles; the extent being limited by the topography as the deposits appear, for the most part, to have accumulated in shallow ponds or in well-defined valleys. The lens-like form has been emphasized by almost all observers in every portion of the Tertiary. Unfortunately the details recorded for most localities are insufficient to justify an attempt at working out the history of any bed, known to exist within a large space. Detailed study is impossible at present in the United States and Canada, where alone the great beds are known, because those occur in regions with sparse population, where, for long distances, one must depend on imperfect natural outcrops or on the less definite lines of clinkered rock, caused by spontaneous combustion of the coal. The perplexity is increased by variations in thickness and composition of the intervening rocks, as well as by similar variations in the coal beds themselves, which make correlation extremely difficult. Several American observers decline to regard the coal deposits as continuous in large areas and prefer to describe "coal horizons." All agree as to the lens-like character of very many beds; even those who are unwilling to accept this for the great beds, frankly present the frequent changes into shale and the local disappearances of the coal as serious problems. Some observers have shown that the lenses often overlap, that a coal thins out and may be replaced by another at a few feet higher or lower. This feature, so characteristic of American localities, was recognized by Credner and by Raefler in the coals of Prussian Saxony.

The rocks intervening between beds of Tertiary coal may be conglomerate, gravel, sandstone, sand, shale, clay, limestone or alternations of such deposits. Ordinarily, these are of freshwater origin, but, not infrequently, one finds layers with brackish-water

fossils and occasionally a bed with typical marine forms. At most localities the bedding is irregular and the rocks seem, in many cases, to be composed of dove-tailing lenses; lenses of fine clay occur frequently. Sandstones and sands are cross-bedded in great areas; ripple-markings and mud-cracks have been reported from many places. Conditions in the western United States appear to indicate that these deposits were made on plains, where the sands drifted and where the water was collected in shallow pond-like areas. The gravels in many cases indicate filled channel-ways.

These intervening rocks frequently contain drifted materials. Leaves and stems of upland vegetation are found in the sands of Siberia; Collier saw cones of *Picea,* bones of mammals, land and freshwater shells in beds overlying Pliocene lignite on the Yukon; Grand'Eury observed wood, roots and spots of lignite at Budweis; Colenso in Wales described a deposit very like that of Alaska; the sections in western North America usually contain reference to these drifted plant remains. But not all the plant remains were transported; at many places they mark old soils of vegetation, surfaces where plants grew, but not long enough for accumulation of coal. There are many references to these in preceding pages and only one need be added. Darwin,[262] in a publication later than his "Researches," gave a detailed description of the petrified forest seen on the Uspallata range of Chili. The stumps, exposed in a small area, were in green and brown sandstone, which had been removed by erosion so as to show the erect stems in place. Fifty-two stumps were examined, projecting 3 to 5 feet—in one case 7 feet—from the surface. Whether or not they were rooted, he could not determine, as the lower part in every case was still buried in the rock. The dip was 25 degrees and the stems were vertical to the bedding. It was suggested to him that the trees might have been transported, but that explanation seemed insufficient; it might suffice for a single stump but not for a clump of 52 trees, which belonged to an inland coniferous flora, not to a coast vegetation. The conditions convinced him that erosion had laid bare only a small part of the forest.

Occasionally, lake marls, interrupted by beds of brown coal,

[262] C. Darwin, "Geological Observations in South America," London, 1846, pp. 202.

accumulated in great thickness, as in southern France. It is evident that some were made close to estuaries, for several observers have recorded that thick deposits, crowded with freshwater fossils, are interrupted by layers containing forms which are unquestionably marine. The intervals between Tertiary coal beds vary so greatly and so abruptly in thickness that, where natural exposures are the only dependence, correlation of beds in any area is difficult, often impossible.

The roof of a Tertiary coal bed may be composed of any kind of rock, transported or formed *in situ*. There are abundant illustrations of transition from the underlying coal to the roof rock, from accumulation of coal to final destruction of plant life on the bog surface, alternating laminæ of vegetable and mineral material testifying to the struggle between silt overflows and the dwindling bog. This faux-toit is a characteristic feature; at times it is merely a carbonaceous shale; at others it is a very impure coal. Very often the immediate roof is distinctly transported material with leaves, twigs and broken bits of wood, even fragmentary trunks of trees. It may be marine shale, rich in fossils, or it may be a marine limestone, as at Häring, containing bits of water-loving plants, such as *Salix, Erica* and palms. Or it may be sand enveloping erect trunks of trees, which grew on the dried surface of the bog, as at Senftenberg or near Friesdorf in the Cologne area. Grand'Eury[263] remarks that the fossil forest in the roof of the great coal bed at Petroszeny, in Hungary, rivals that of Purbeck and that the trunks, erect, are rooted on the top of the coal, while around the stems at the bottom of the deposit are branches of *Taxodium distichum,* clearly fallen from the stumps. A similar condition is reported from localities in the United States and in Europe. At times, the roots of trees growing in the faux-toit, pass downward into the coal as described by D. White for a mine in Texas and by other observers in places where the stumps are rooted in the coal. Grains of coal are not rare in the roof or the accompanying rocks, showing clearly that a coal deposit had been exposed to erosion. In much of the Oligocene areas of Prussia, the original roof has been removed and has been replaced with late drift material. The gradual disappearance of coal-forming

[263] C. Grand'Eury, *Comptes Rendus,* T. 130, 1900, p. 1689.

conditions is shown very frequently by a faux-toit; but not rarely the passage from coal to roof is abrupt, which may indicate, perhaps, that peat-making had ceased for some time prior to the burial under transported material.

The coal beds are rarely single; they are divided by partings into benches, which differ greatly in thickness and in composition, though there are beds which are remarkably uniform in composition throughout. The coal may be hard or soft, massive or laminated, and the several types may be in separate benches or even in the same bench. Generally, the coal is hard enough to require the use of heavy tools in mining so that it comes out in lumps, Knabben- or Knorpelkohle of the Germans. This type is especially characteristic in the United States. But in somewhat extensive areas within Germany one finds abundantly the other type, Form-, Fein-, Rieselkohle of the various localities, fine-grained, earthy in appearance and but slightly coherent. All types of coal, enumerated by authors, may be found in a single bed or even in a single bench. Fragments of wood are numerous, lignite at one end where the annual rings are distinct, while at the other end they have been converted in shining Pechkohle, apparently without trace of vegetable texture. A similar condition is seen in many cases of replacement, for one part of a stem may be wholly silicified while the other remains wood. In such cases, the original structure frequently remains distinct, whereas in replacement with dissolved carbon compounds, as in Pechkole, the structure disappears. The distribution of Formkohle in a bed is indefinite; it may occupy the whole space from floor to roof, interrupted only by partings; it may be at the bottom or at the top, or it may alternate with benches of other coals. Its mode of origin is discussed elsewhere by the writer.

Macroscopically, the coal consists of various fragments of organic and of inorganic origin, embedded in a structureless mass, in which the unaided eye can find no trace of texture; but under the microscope, this structureless mass proves to be minutely divided plant débris. Woody materials are often predominant, occasionally more than three fourths of the mass. Logs are reported from all localities, but they are distributed irregularly through the deposit, at least

as a rule. At times, prostrate stems as well as rooted stumps are abundant especially in the lower portions, but at others they occur within definite horizons in the higher portions; the smaller fragments are frequently converted into mineral charcoal. These conditions, observed in widely separated American localities, are similar to those observed in many European places, though, there, mases of logs are not so common as in the American lignitic coals; but the logs are found in all sorts of coal, Formkohle as well as Knorpelkohle and, many times, they are of enormous size. Prostrate logs are, with rare exceptions, compressed, often so compressed that it would seem as though only the bark remains, but erect stumps are very rarely compressed. Leaves and the strongly compressed stems appear as impressions on the structureless débris though occasionally, as at Bovey Tracey, leaves may form the great mass as slightly compressed logs do elsewhere. The logs belong mostly to conifers and they have been preserved because of the resin-content. The débris, formed from the softer, more readily decomposed plants and portions of plants, contains spores, pollen grains, bits of dicotyledonous plants as well as of the softer parts of conifers. The disintegration and decomposition of the material has led to enrichment in resins, as shown under the microscope. Replacement of wood is common, the replacing material being for the most part, silica, pyrite, calcium and ferrous carbonates; this replacement has been observed in the peaty material of the débris, giving the nodules, which Gothan and Hörich have termed torfdolomite.

Animal remains have been found in coal at many localities. Sedgwick and Murchison, as well as Anker, discovered bones of mammals in the Eocene bogs of Styria; Katzer saw teeth and bones of mammals in the Banjaluka coal; Fournet saw abundance of land and freshwater shells in the French lignite; v. Gümbel observed *Helix* in some layers of Pechkole in southern Bavaria. The dysodil or Blätterkohle of the Lower Rhine region contains many species of batrachians, fishes and insects, while that of southern France is closely packed with fish remains, retaining at some localities much of the original animal matter. Inorganic materials are normal constituents of coal; some of the admixture is due to silicious organisms,

for diatoms are of common occurrence, occasionally following important deposits; a greater proportion is derived from the mineral content of the coal-producing plants themselves; but when the quantity is considerable, the most of it is of extraneous origin. Pockets of sand and silt have been reported by almost all observers. The silt is often distributed intimately throughout the coal or it may be collected in thin laminæ, such as render the coal worthless, or it may be in comparatively thick partings; even pebbles of rock have been reported from a few localities.

Brown coal deposits, with rare exceptions, are broken by partings. These may be so thin as hardly to be seen by the unaided eye, yet they are distinct, for the coal separates on their planes; they may be a foot or more in thickness and composed of any material transported or formed in place. Each definite parting is roof to the underlying, and floor to the overlying coal. Roots, leaves and freshwater, as well as land shells have been reported from clay partings in Hungary and Bosnia, leaves from New Zealand and Borneo and freshwater shells from shale and marly limestone partings in France. References to other regions are in preceding pages. Each parting is evidence of interrupted coal-accumulation; but its thickness at any place is no evidence respecting the duration of the period of interruption, for the thickness is a variable quantity. Russwurm notes a parting which increases from 0.5 to 4 meters within a short distance; near Gran in Hungary is one which is 1.9 meter in one mine but 17.45 meters in another, only a little way off; Evans has described one in Washington, which thickens from 4 to 90 feet within a horizontal distance of 3,200 feet, while in another direction it quickly decreases to 10 inches. Such variations are due to merely local causes as the deposits, for the most part, are of very limited extent. The changes are comparable to those observed in the rocks intervening between coal beds, often so great as to make correlation of the coals difficult. The partings, which consist largely of mineral charcoal, are important, as they appear to be often persistent throughout a basin; yet they are rarely more than half an inch thick. These indicate a positive change in conditions which made growth of vegetation imposible and led to exposure of the peaty surface to atmospheric

action. A layer of mineral charcoal and minutely divided inorganic matter may be the residuum from a considerable thickness of peat; the proportion converted into mineral charcoal and so rendered practically indestructible would be small compared with that wasted by oxidation and removed by the wind.

Evidence of long-continued interruption of ordinary peat formation is afforded by forest beds within the coal deposit. At Senftenberg, as shown by Potonié, the surface of the bog became dry enough, more than once, to permit growth of trees; in the Cologne-Linz area, the dryness was such and the period so long that a forest, containing trees with 1,600 annual rings, had full opportunity for development. In much of the Cologne region, the vast proportion of the stems are prostrate, but that condition is by no means evidence that they are in any but the place of growth. They are merely overturned trees as are those of the white cedar swamps of New Jersey or those in the cypress swamps of Florida or the bogs of Borneo. One layer in the Cologne-Linz district is a meter thick but erect stumps are present among the prostrate stems, as Horner and Heusler have shown. Trees of such immense size as those described by Horner indicate a very prolonged period of comparative dryness, during which the peat, as soil for the trees, was protected from wasting by offal dropping from the dense forest cover. A somewhat similar condition was noted by Wegemann in the Barber coal field of Wyoming.

The floor of coal beds is as variable as the roof, but it is usually clay or marl. The transition from the coal is occasionally abrupt, but in most cases the passage is gradual, through a faux-mur, consisting of alternating layers of coaly material and the mur rock. Very frequently the mur contains fresh water shells, that condition being reported from many places in all parts of the world. Land shells are not rare; they may have been floated in or they may mark drier places in the swamp. Leaves are found frequently in the marls and clays. The notable feature of the mur is the presence of roots attached to stems projecting into the overlying coal. At times the roots alone remain recognizable, the stems having been merged in the coal. Usually these are those of swamp types; but in cases

where the stumps project into the coal other forms may occur. The classic illustration is that at Senftenberg, described by Potonié, where one sees complete evidence of destruction of a forest by a transgressing bog. Kukuk's photograph of wholly similar conditions is equally conclusive. Not rarely the stumps had become hollow before entombment.

No complete statement respecting the flora of the brown coals can be made; the plants obtained from the associated rocks cannot be utilized as they are enclosed in rocks of transported material and represent, in part at least, the upland flora; they are as inconclusive as would be lists of forms found in the clays and sands which had slipped down on a swamp, to one endeavoring to determine the plants of peat. It is necessary to confine one's investigation to such information as can be obtained from the coal itself, though in some cases evidence from the enclosing shales may be utilized as illustrating prevailing conditions in the immediate vicinity.

The logs and stumps within the coal beds are almost invariably conifers. In Greenland and Spitzbergen, recognizable remains are rare in the coal and the logs are usually silicified; but the associated shale shows that, during its deposition, the prevalent types of the immediate vicinity were conifers and other forms of acid-loving plants, a swamp flora, so that swampy conditions prevailed in the area whence the shale material was drawn. The Pliocene coal of Hungary is crowded with stems of *Sequoia;* the Miocene swamp of Virginia contains *Taxodium, Nyssa, Salix, Quercus* and other types belonging to genera familiar in recent cypress swamps. At Bovey Tracey in the Eocene, ferns and *Sequoia* predominate, yet at the bottom of one bench there is a mass of dicotyledonous leaves. Fournet found a typical swamp flora in the Vion lignite, where he recognized birch, juniper, fir, cherry and walnut, with sedges and rushes. Daubrée, near Lobsann on the Lower Rhine, found that the mineral charcoal is from conifers while the peculiar fibrous coal, his lignite bacillaire, which forms the greater part of some deposits, is derived from Palms. At Senftenberg *Taxodium distichum* is the prevailing type in the coal, but in the upper layer are stumps of *Pinus* or *Picea.* Conifers and palms are the most abundant types in

the Hardt district of the Cologne-Linz region. The woody fragments in Brandenburg mines are practically all from conifers; in Sachsen, the fossil wood is coniferous, belonging almost wholly to the cypresses; but at Tanndorf, where the conditions are well shown, Penck found *Salvinia* and *Trapa* in the lower portions, succeeded by a layer with *Arundo,* which is followed by normal peat with *Betula* and *Palmacites.* Reuss's collections from the fetid limestone roof of the Häring coal show that the coal was formed at the head of an estuary for, mingled with remains of marine animals, it contained abundant fragmentary remains of *Salix, Erica,* palms and other swamp plants, which, it would seem, must have been torn away from the still living swamp on the shore, continuous with the buried swamp which has given the Häring coal. American localities tell the same story respecting the woody materials. Grand'Eury,[264] in summing up the results of his studies, asserted that in the lignite areas of Tertiary age he had found as many stumps with roots and branches *in situ,* as in Carboniferous coal basins. From their position, even in the midst of rocks and limestones, it is to be presumed that the *in situ* roots are evidence of plants growing on bottoms subject to inundation. The flora shows instances of local variation, one striking illustration being that recorded by Heusler in the Cologne area.

Very few observers have given detailed record of localities where evidences of contemporaneous erosion are distinct. The writer has made careful comparison of sections preserved in basins of considerable magnitude and he is convinced that the variations in coal and the intervening rocks are such in many areas that they can be explained as due only to contemporaneous erosion. The absolute proof of such erosion cannot be secured except where coal mining has been well-developed—and there are few such localities in the American Tertiary. European basins are small and the petty variations due to contemporaneous erosion are easily overlooked. Very clear cases of such erosion have been reported from the interval rocks of Wyoming but in no case is the extent fully revealed. Evans has shown that in Washington some coal beds have suffered severely

[264] C. Grand'Eury, *Comptes Rendus,* T. 138, 1904, pp. 666 ff., 740 ff.

and that, in considerable spaces, the coal has been removed and has been replaced with sandstone.

The intimate resemblance of many brown coal deposits to those of peat has been affirmed by many observers. Collier recognized the resemblance in Alaska and Washington as did Eldridge in Alaska; Haast was positive respecting it in southern New Zealand; several authors have described the Moor- and Mooskohle of Prussia and Bohemia; Gothan and Hörich have shown that the Torfdolomite of the Lower Rhine is merely mature peat replaced by inorganic matter; Smith and Travers[265] described as peat an impure brown coal underlying the London clay. In many places the coal has been found resting on the characteristic reed beds.

Few students have made minute investigation of the structure and succssion of individual beds. Penck's observations at Tanndorf have made clear that the brown coal at that place is in a lake basin; the muddy floor afforded roothold for floating plants, on whose débris rushes and other plants of similar habit grew, until the surface became such as to permit growth of shrubs and trees. Others have reported the occurrence of swamp plants in the brown coal, but they have not said anything about their vertical distribution in the deposit. Similarly, the presence of land and freshwater shells has been noted by numerous writers, but there is rarely any information as to their distribution in the bed. All that one may assert is that these indicate the existence of pools or ponds in the marsh. Expansion of the accumulating area by transgression, after the manner of swamps, is distinct at many places. Stohr has shown that in a part of Prussian Sachsen, the deposit began on an irregular surface as a number of separate lenses, which often became united by crossing the dividing ridges; so that the coal is from 0 to 20 meters thick, being thinnest on the low rolls separating the narrow troughs. D. White's description of conditions at Lehigh, North Dakota, is wholly similar; the greatest thickness is in the hollows of the floor and the coal becomes thinner toward the "rise." At Senftenberg and Orebkau, as appears from description by Potonié and Russwurm, transgression upon forests is clear. At Senftenberg, the forest was living when the marsh

[265] W. Smith and M. W. Travers, *Journ. Soc. Chem. Ind.*, Vol. XI., 1892, p. 591.

invaded it, and the stems, still erect, extend into the coal; but at Orebkau, the condition appears to have been different. There, logs increase downward until at the bottom they constitute practically the whole mass. The forest growing in loose material must have been overthrown, for in the mines examined by Russwurm, no erect stems were seen. Many beds of brown coal seem to be wholly without tree trunks, just as there are many peat bogs without fragments larger than a twig; these had not reached the stage of tree-growth. Interruptions in growth are equally characteristic of peat bogs and brown coal beds. Some are shown by partings containing much mineral charcoal, others by partings of transported mineral matter, while others still by the forest layers. At Bovey Tracey, a great mass of leaves in the lower part of a thick bench is the remaining evidence of a dicotyledonous forest, whose non-resinous stems have disappeared. A succession of forests is shown at Senftenberg, even to the last, which was entombed in the covering sands as was that at Wurzen in Sachsen. The great forest bed of the Hardt area marks a long, though not total interruption; growth of normal peat ceased for the time, but accumulation most probably continued; offal from coniferous trees accumulates to notable thickness in many parts of the world without injury to the trees; Capps has shown that in Alaska, where the plane of perpetual frost is at only a few inches below the surface, the gigantic spruces adjust themselves to the conditions and throw out new sets of roots as the peat surface rises.

The benches of a coal bed often are dissimilar. One finds no evidence of widespread climatic changes during the period of a single bed's growth. In most cases, there is evidence of notable variation in moisture conditions and dryness appears in some localities to have prevailed for long periods; but there is no evidence that these variations were due to any but local causes. They are much like those which may be seen in almost every peat deposit. At Bovey Tracey, one bench is composed almost wholly of fronds of ferns while another is a mass of *Sequoia* stems; near Budweis, the upper bench contains stems completely coaled, while the lower bench is composed mostly of the imperfectly changed Moorkohle. Hantken has described a bed of which the upper part is woody, crowded with

Sequoia, while the lower part is hard coal. At Orebkau, the upper bench is Knorpelkohle, with very little wood, while the lower bench is Formkohle with much wood. Variations of similar type are reported from American localities and they are such as are familiar to students of peat deposits. They are so characteristic that one finds it difficult to avoid the conclusion that, as in peat bogs, the process of conversion was arrested in some benches while it continued in others. It seems hardly possible that the differences developed after burial, as conditions since that time must have been practically the same for all portions of the deposit.

The differences in physical features are accompanied by differences in chemical composition. The lower portion of the coal bed on Advent Bay, Spitzbergen, has 9 per cent. more volatile than is found in the upper portion. Coals from different parts of the same mine show even greater contrast; 18 per cent. near Gran in Hungary, 23 near Brennberg in the same kingdom, 35 at Glendive in Montana; and similar variations are shown by analyses of samples from neighboring mines on the same bed. The ash content tells the same story; in six mines on the same bed, near Rockdale, Texas, the ash varies from 9.43 to 24.67. The comparison is more instructive when one considers the composition of the ash, for the samples analyzed were prisms representing the full thickness of the seam, only such partings being removed as should be separated before shipment of the coal. The silica is from 21 to 47 per cent., alumina from 12 to 28, ferrous oxide from 2 to almost 25, lime 6 to 38 and sulphuric acid 4.58 to 18.01. These samples were taken in an area of probably not more than 2 or 3 square miles. It would appear that conditions during accumulation varied greatly in the different parts of even small areas, just as they do in the swamp areas of this day.

Sapropelic or Lebertorf material is an important constituent of many swamps, though there are very many in which no trace of it exists. It has been reported occasionally from the Tertiary coal. Dall obtained at Amalik Harbor, Alaska, a dull coal which contains 81.26 per cent. of volatile matter; at Mendota in Washington there are lenses of what appears to be Lebertorf, the coal having all the features of cannel and burning with a long smoky flame; lenses of

wholly similar material were observed by D. White at Hoyt, Texas; the same observer has described the cannel-like material of the Lester bed in Arkansas, very rich in oils and in gas of high candle-power; it is rich also in spores and pollen exines. Tertiary "oil shale" of high grade is reported from New Zealand. The mode of occurrence and the chemical as well as physical constitution indicate very close relationship to the Lebertorfs. Pyropissite presents some problems not yet wholly solved, though they have attracted attention from many students; but there appears to be little evidence to support the hypothesis that it is merely the resin of the original plants, concentrated by physical agencies during transportation of the more or less converted peat or brown coal; while there is much to suggest that it is related to the Lebertorfs. The condition is different in the case of dysodil or Blätterkohle; that is without doubt of sapropelic origin. It occurs in lenses, sometimes at the bottom, at others in the upper portion of a bed, while, occasionally, it forms the whole mass. This contains abundant remains of aquatic animals, spores, pollen and, at times, is rendered almost worthless by the great proportion of diatomaceous earth.

Haidinger, in studying the Faserkohle from the Häring deposit, discovered that it contained a material, which he believed was introduced when in the condition of dopplerite, a soluble constituent of peat; D. White in several publications has maintained that the jetified wood, so abundant in the xyloid Tertiary coals of the United States, owes its character to the infiltration of dissolved products of vegetable decomposition. Glöckner reached the same conclusion respecting the "Glanzkohle" of Zittau. Von Gümbel regarded the "Carbohumin" or cementing material of brown coal as merely dopplerite which had passed over to the insoluble condition. Dopplerite, as the analyses show, is not a true mineral but is a mixture of various humic or humic and ulmic compounds, which after losing an indefinite proportion of water, is so changed that it cannot regain plasticity even by prolonged submergence in water. The zittavite of Glöckner appears to be a wholly similar substance; the terms dopplerite, Carbohumin and zittavite indicate the geological horizons of the occurrence.

The carbon content of brown coal varies; in a general way it gives proof of great advance over peat, yet in many localities the process of conversion stopped short of the stage reached by most of the fuel peats of which analyses are available. Pliocene coal of Bavaria has from 62 to 69 per cent.; Miocene coal from one mine in Bavaria has but 49, the Édéleny coal of Hungary has but 54 and the Grottauer coal in Bohemia has 53; but in other localities in Bavaria the carbon is almost 71 and near Brennberg in Hungary it is 72. The Oligocene coal in the Gran-Comorn district of Hungary shows 65 to almost 74; the Brandenburg coals have 60 to almost 71, the Zeitz area of Sachsen 64.78, and the Cologne area only 62. Eocene coal of Bovey Tracey has almost 70; coal at Rockdale, Texas, contains 67.36 to 77.11 in samples from several mines on the same bed. In the northern areas within the United States, there are few analyses showing less than 70 and some reach 75, but in Alaska coal from most of the beds has from 64 to 70. In Alaska and Washington, there are localities where the carbon content is much higher, but those do not concern the matter in hand, as there is reason to look upon them as more or less metamorphosed.

Beyond all question, there is at most localities distinct evidence of progressive enrichment in carbon with loss of oxygen as one descends in the scale. The extremes of carbon content in peat are 40 and 64; in the Miocene, 49 to 72; in the Oligocene, 58 and 70, in the Eocene, 64 to 79. At the same time one must recognize that, as in peat deposits, the progress of change was checked in some localities at a much earlier stage than in others.

INTERRELATIONS OF THE FOSSIL FUELS.*

II.

By JOHN J. STEVENSON.

(*Read April 14, 1917.*)

THE CRETACEOUS COALS.

Coal of Cretaceous age occurs more or less abundantly in many countries. The original areas in which it was formed vary from mere patches to thousands, even hundreds of thousands of square miles; but these greater areas have been broken by erosion into isolated basins, or better into isolated fields, sometimes widely separated. The coal seams are not confined to a single horizon but are present throughout the Cretaceous at localities where proper conditions existed. The several regions have so many features in common as well as so many in contrast that a detailed description of some typical areas, though tedious, is necessary for proper understanding of the relations.

Europe.

In western Europe, coal is confined almost wholly to the Wealden but in central Europe the Upper Cretaceous contains deposits of more than local importance.

Coal in thin seams has been observed at some places in England but the quantity is significant. The Wealden of the Dorsetshire coast and of the Isle of Wight has no coal. Mantell[1] states that, at Brook Point on the Dorset coast, a sandstone ledge in Lower Wealden encloses trunks and large branches of trees, mostly petrified. Webster, at an earlier date, had seen these stems, of which some had been converted into a jetlike substance. Mantell, observ-

* Part I. appeared in these *Proceedings*, Vol. LV., pp. 21–203.

[1] G. A. Mantell, "Geological Excursions round the Isle of Wight," 3d ed., London, 1854, pp. 203–206, 238, 239, 242.

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ing that all the stems are prostrate, thought them a fossil raft, remains of an ancient pine forest, transported by a river and buried in the delta sands and muds, as is the case with rafts of the Mississippi River. But the description of conditions leads one to hesitate before accepting the reference to rafts. The Mississippi rafts, as described in European works of Mantell's day, were not the rafts as they were. It is not probable that the rafts of the Atchafalaya and Red River would produce deposits such as those under consideration. The features[2] are more like those observed along the Athabasca and some other North American rivers, where great masses of driftwood occur, the interstices being filled with silt and sand. Mantell emphasizes the presence of ripple markings in the Wealden; slabs of sandstone, clay and limestone on the Isle of Wight are often covered with them. Imprints of annelid and molluscan trails, of crustacean claws, of pectoral fins of fish as well as of feet of reptiles have been obtained. The formation is of essentially fresh-water origin. Lyell,[3] in describing the Lower Wealden or Hastings sand, remarks that one finds at different heights in the section strongly rippled slabs of sandstone. Some of the clay beds had been exposed, for sun cracks are abundant. A red sandstone, near Horsham, contains innumerable traces of a plant, apparently *Sphenopteris,* with stems and branches disposed as if they are standing erect on the place of growth, the sand having been deposited gently around them. Similar conditions have been observed elsewhere in this formation.

Some coal has been found in the Wealden of France, but it is of little importance. The lignites of Simerols[4] suffice as illustration. The area is small, with radius of about 25 kilometers. The section at one locality shows (1) clay, 0.90; (2) lignite, 2.50, at times without partings, but at others divided into two or three benches; (3) shale, 0.70; (4) lignite, friable, not mined, 1.50; (5) carbonaceous shale, 0.80; (6) lignite, compact, 1 to 1.50; total, 7.90 meters. This deposit, at times only 4.60 meters thick, underlies

[2] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.,* Vol. L., 1911, pp. 548–551.

[3] C. Lyell, "Elements of Geology," 6th ed., New York, 1866, pp. 350, 351.

[4] Arnauld, "Des argiles lignitiferes des Sarladais," *Bull. Soc. Geol. France,* II., Vol. 23, 1866, pp. 59–63; Meugy, the same, pp. 89–96.

marine Cretaceous, but is of fresh-water origin, the animal remains being indeterminate bones with shells of fresh-water mollusks. Plant remains and silicified stems are in the clays. The lignite is described as compact, blackish brown and lusterless.

The Wealden of Hanover, that portion equivalent to the Hastings sand of England, has coal seams, which in many places have economical importance. The region[5] has been studied by several geologists, each having in view the study of some special features. The area has extreme length from east to west of about 160 miles and an extreme width of about 120 miles from north to south. Exposures are not continuous, for erosion has removed the Wealden from extensive spaces, while in others the surface rocks belong to later formations. According to Credner, it reaches from the Harz Mountains westward to the Holland border, where it passes under a thick cover of diluvium. The exposed areas are isolated and at times are so widely separated that sections have little resemblance. The Wealden consists of clays, marls, sandstones and coal beds; the colors are from white to gray, with rare bands colored by oxide of iron. Dunker states that the coal usually resembles the older black coals, the plant materials have undergone much greater change than in brown coal, and distinct woody structure is rarely recognizable. Some mines yield a coal comparable to the best in England; a sample, analyzed by Regnault, gave carbon, 89.50; hydrogen, 4.83; oxygen and nitrogen, 4.67; ash, 1. This type is dense, brilliant, with uneven to conchoidal fracture and in appearance resembles anthracite. It is closely jointed and usually has a blackish brown streak. But there is lignite in the Wealden, with woody structure and reddish brown streak. A sample from Helmstadt, analyzed by Varrentrapp, yielded carbon, 68.57; hydrogen, 4.84; oxygen and nitrogen, 19.87; [ash, 6.72]. Dunker thinks this brown coal derived from conifers, cycads, lycopods and ferns.

In the Osterwalde, a very different type, the Blätterkohle, is

[5] W. Dunker, "Monographie der Norddeutschen Wealdenbildung," Braunschweig, 1846, pp. xi–xxviii, 2, 21; Heinrich Credner, "Ueber die Gliederung der oberen Juraformation und der Wealden-Bildung im nordwestlichen Deutschland," Prag, 1863, pp. ix, 47–54, 132, 138, 133, 138–141; C. Struckmann, "Die Wealden-Bildungen der Umgegend von Hannover," Hannover, 1880, pp. 14–28, 30–36.

found in the same section with other coals, some of them belonging to the "black coal" type. This Blätterkohle consists chiefly of *Abies linki* and *Pterophyllum lyellianum,* whose densely packed leaves and twigs, mostly brown and transparent, become flexible, when soaked in water; coalification is extremely imperfect. Dunker thinks that lycopods and ferns are the chief constituents of the black coals, as no remains of other plants have been discovered. It may be noted in passing that the Blätterkohle bears great resemblance to the conifer peat of the Fichtelgebirge,[6] as described by Reinsch, and to the "coarse" coal of the Carboniferous; in the latter the conversion is complete. It must not be forgotten that David discovered equally flexible remains of plants in the Permo-carboniferous of New South Wales.

The coals vary in quality; partings thicken and at times the whole seam becomes carbonaceous shale; occasionally masses of silicious matter, limestone or pyrite become so abundant as to render the deposit worthless. In some mines, a waxy substance, clear or dark yellow, occurs, which Dunker thinks may be hatchettin.

Near Bückeburg and Schaumburg, the Wealden sandstone is 120 to 150 feet thick and contains 4 coal seams, of which two are workable. On the Osterwalde, the thickness is not far from 450 feet and 18 seams were seen, mostly thin or too poor in quality to justify mining, the greatest total thickness of coal being 9 feet. Well-marked coal seams, in nearly every case, have a black clay roof and floor, the latter occasionally passing into Brandschiefer or cannel shale. The roof clay, at times, contains abundance of plant impressions and even becomes coaly—a true faux-toit. In the upper part of the section there are two seams consisting mostly of the black coal, but this, in part, is continuous with brown coal, containing pieces of wood-like anthracite.

The plants enumerated by Dunker include 2 species of *Equisetum,* 26 of ferns, 10 of cycads, 5 of conifers and one palm, *Endogamites,* now taken to be *Sedgwickia.* One species of *Equisetum* occurs abundantly in a sandstone, where the stems are more or less nearly vertical. Stems of trees were observed at many localities;

[6] See "Interrelations of the Fossil Fuels, I.," *Proc. Amer. Phil. Soc.,* Vol. LV., 1916, p. 54.

those replaced with sandstone or oxide of iron show no trace of structure, but those from the coal resemble *Pinus*. He believes that much of the coal is derived from conifers.

Credner reports that the sandstone is 540 to 550 feet thick on the south slope of the Diester range, 8 to 12 miles south from Hannover, where it consists of alternating clay shales, marly shales, sandstones and stone coal; the chief mass is a yellow, fine-grained sandstone with little cementing material. The section shows 16 coal seams, of which 11 are less than 10 inches thick and have "bad coal." Three beds, 2 feet, 1 foot 6 inches and 1 foot respectively, are of "workable" thickness and yield good coal. Clearly, the periods when coal accumulation was possible, were of brief duration and the general conditions were not such as to encourage formation of good coal; the total thickness is little more than 15 feet, of which less than one third is good. The fauna is fresh-water, *Unio, Paludina, Cypris, Lepidotus* and *Sphærodus* being the prevailing forms; *Cyrena* is not rare. The flora consists of ferns, cycads, conifers and palms.

The Osterwalde area is farther west; its resources had been developed after Dunker's examinations were made. The Wealden sandstone is approximately 500 feet, but the conditions are not the same as in the Diester area. The "workable" coal seam, one foot thick and 28 feet above the base at Diester, is here in the same position, but only 8 inches thick. Within 72 feet above it are 3 seams, the thickest being 6 feet 9 inches, all absent from the Diester section. Near Minden, 7 miles farther west, the coal is thicker. Meanwhile the character of sediments has been changing, for the sandstone, predominating at Diester, is insignificant here. The change continues westward: at Bentheim and Ochtrup, on the Holland border, one finds only clays and limestones about 800 feet thick; the limestones yield *Melania* and *Cyrena*. According to Credner's descriptions, it is evident that the coal decreases in the direction of finer sediments. The thick coals of Minden are associated with the one noteworthy sandstone of that area. Both Dunker and Credner note abundance of sphærosiderite in the rocks associated with coal seams.

Studies by Dunker and Credner were mostly in the region west from Hannover; Struckmann gave information respecting other

areas and added to that respecting the western. The coal-bearing deposits equivalent to the Hastings sand are his Middle Wealden; his Lower Wealden is equivalent to the Purbeck beds of England, now placed in the Jurassic. The whole Wealden of Struckmann is only 15 meters thick under the city of Hannover; the Hastings sand is thin but contains an unimportant seam of coal. At Neustadt, 16 miles farther northwest, the sand is still present, though very thin, and holds thin coal, which has been utilized. At 24 miles west-northwest, the sand is insignificant, almost wholly replaced by a thick, often bituminous clay and marly shale, shale, rich in pyrite, but holding some coal.

The Hastings sand increases southwardly. At 10 miles west from Hannover, thick beds of sandstone appear; on the Diester, south from that city, as well as on the Süntel ridge at the southwest, sandstone prevails; but at Osterwalde, sandy and clayey shales are abundant, though there are prominent beds of sandstone. Struckmann compares several sections, I., on the Diester by Credner; II., farther west by himself; III., on Osterwalde by Credner; IV., at Rehburg, northwest from Hannover, by himself:

	I.	II.	III.	IV.
Sandstone	118.63	124.33	47.00	6 to 7
Clays, marls, sandy shale, soft sandstone	40.00	37.62	110.00	114.00
Coal, worthless	2.06	0.87	3.00	0.00
Coal, workable	1.31	0.84	2.50	0.23
Total, meters	162.00	163.66	162.50	120.00

In I., there are 12 worthless seams and three workable; in II., 3 worthless and one workable; in III., 6 worthless and 5 workable; in IV., one workable.[7] In III., sandy shales or very slightly consolidated sandstones, but in IV. clays and marls make the greater part. These observations by Struckmann show that the source of sediment was south from Hannover and that the sand flats decreased toward the west and north, giving place to less coarse materials. The coal seams are irregular and it is evident that many of them are of insignificant lateral extent. Sphærosiderite is abun-

[7] It would appear that in these calculations any seam yielding good coal and more than ten inches thick is thick enough to be mined.

dant. The fauna is fresh-water. The flora at Osterwalde consists of ferns, cycads and conifers, but two forms, an *Anomozamites* and a *Spirangium*, are wanting there, though they are extraordinarily abundant on the Diester.

Hosius[8] discovered plant remains and fragments of coal in the Wealden sandstone near Vreden in Westphalia about 35 miles west-northwest from Munster.

The Upper Cretaceous is almost wholly marine in England, France and western Germany, so that coal occurs rarely and in small quantity; but farther east, in Saxony, Bohemia, Silesia and Moravia, the limestones and marls are replaced with sandstones at several horizons and coal deposits are present, which in some areas have much economic importance.

The Löwenberg basin in southern Silesia is at about 25 miles from the border of Saxony and Bohemia. According to Scupin,[9] the coal of this basin has been regarded as either stone or Pech coal; it is deep black, lustrous and has conchoidal fracture, but gives a very dark color to solution of caustic potash. It is of merely local importance, as the greatest thickness is little more than a half meter, yet at one time the annual output was 60,000 Centner. Near Klittsdorf, a sandy brown coal contains remains of wood; near Löwenberg, coal, 6 inches thick, is exposed and lower down in the section is a mass of coal and sand, containing 6 inches of good coal, but in greatest part is mixture of coal and sand in about equal proportion; at another exposure the composition is clay and fragmentary coal. Scupin thinks that this confused mass must be allochthonous and suggests that it may represent a washed out swamp. Two lower beds, 10 and 3 inches thick, were pierced in a boring and a notable quantity of sphærosiderite was found in the intervening rocks.

The Cenomanian coal of Bohemia is usually unimportant. Naumann says that the Lower Quadersandstein occasionally contains layers of clay shale rich in conifer and dicotyledonous remains, with nests and layers of mostly unworkable coal. v. Andrian gives the section obtained near Chrudim, about 60 miles east-southeast from Prag: (1) Coarse sandstone, with fossils, 24 feet; (2) dark clay

[8] Hosius, *Zeitsch. d. d. Geol. Gesell.*, Vol. 12, 1860, p. 61.

[9] H. Scupin, "Die Entstehung der Niederschlesischer Senon-Kohlen," *Zeitsch. f. pr. Geologie*, 1910, pp. 254–257.

shale, with plant remains and coaled stems, 4 to 5 feet; (3) moderately coarse sandstone, 2 to 3 feet; (4) coarse conglomerate, 2 to 4 feet. The dark shale of this region section contains near Skutsch, 12 miles farther west, a bed of worthless Pechkohle, which is rich in Bernstein. Reuss, in a letter to Beyrich, stated that a mass of Bernstein, several inches long and of brownish yellow color had been obtained as Skutsch, which is very near the Moravian border.[10]

In Moravia, according to Reuss,[11] the coaly substance, to which the Lower Quader beds owe their color, is sometimes collected into nests or even into beds of workable thickness. At a mine, west from Mährens-Trubau and about 50 miles southwest from Chrudim, he saw a seam of thinly laminated Moorkohle [a peat-like brown coal] 4 feet thick, brownish-black and containing laminæ of bright black Pechkohle. It slacks readily on exposure and is high in ash. Grains of honey-yellow Bernstein, some as large as a pea, are scattered through it. The roof and floor are blackish-gray shale. In older mines near Utigsdorf, farther south, Reuss saw two coal seams, 1 foot 6 inches and 3 to 4 feet thick. Coal of the upper bed is brown-black, with shaly structure, rather bright fracture and contains much resin. The coal of the lower bed is black, rather crumbling, contains numerous layers of Faserkohle as well as many lumps and half-inch layers of Pechkohle. Bernstein is less abundant than in the upper bed. Roof and floor of both beds are dark, more or less sandy.

Coal has been mined for many years in Lower Austria, near Grünbach, at a score of miles south from Vienna and near the border of Hungary. The deposits are in the Gosau formation, which is taken to be of Turonian or Senonian age. Cžjžek[12] states that the seams are all thin south from Grünbach, but become thicker north from that city. The Alois tunnel, 1,200 feet long, intersects 21 seams of which only 3 are workable, the others being from 2 to 10 inches thick. The workable beds, all within vertical distance of

[10] Reuss, *Zeitsch. d. d. Geol. Gesell.*, Band III., 1851, p. 13; F. v. Andrian, *Jahrb. k. k. Geol. Reichsanst.*, Vol. XIII., 1863, p. 207.

[11] A. E. Reuss, "Beiträge zur geognostichen Kenntniss Mährens," *Jahrb. k. k. Geol. Reichsanst.*, Vol. V., 1851, pp. 727–731.

[12] J. Cžjžek, "Die Kohle in den Kreideablagerungen bei Grünbach," *Jahrb. k. k. Geol. Reichsanst.*, Vol. II., Pt. 1, p. 144, Pt. 2, pp. 107 et seq.

60 feet, are the *Caroli,* 2 to 3 feet, very irregular in thickness, but its coal is much prized, as it is low in ash and clean, the bed being without a parting. *Jodahofer,* 3 to 4 feet, is usually quite regular, but at times the intervening rocks disappear and this unites with the Caroli, the thickness increasing greatly and occasionally reaching 10 feet. *Antoni,* 2 to 2 feet 6 inches, is in 3 benches with clay partings, each 2 inches. The coal is soft in top and bottom, but in the middle bench it is hard. The roof is black slate, 1 foot, which burns well. As described by Cžjžek, it is a cannel-shale, a mud very rich in organic matter.

The coal is pitch-black, with bright luster and black-brown streak. No woody structure is visible to the unaided eye. Occasionally one finds pieces which retain the form of branches, but all trace of fiber has disappeared. Analyzed by Schrotter, the composition is: Carbon, 74.84; hydrogen, 4.60; oxygen [and nitrogen], 20.56; water at 100° C., 6.57; ash, 6.92. Reasoning from this analysis, Cžjžek concludes that the character of a coal has some relation to its age. The Tertiary coal at Brennberg has only 60 to 70 per cent. of carbon, while that from the Lias at Fünfkirchen has 85 to 86 of carbon and only 8 to 9 per cent. of oxygen.

Passing over into Hungary, one finds, according to Hantken,[18] important development of Cretaceous coals in the province of Bakony and in the western mountains. The areas are insignificant in comparison with those of the Lias, but the beds are little disturbed, mining is simple and the output is large. The important mines are near Ajka in Bakony, where the Cretaceous consists of two marine formations separated by a fresh-water formation with coal seams. The fauna contains some brackish-water forms but fresh-water types predominate. There are at least 25 seams of coal, of which one near the top and another near the bottom are workable. The upper or Bernstein Flotz is always divided into several benches and the coal is inferior. In one part of a mine this bed is 2.93 meters thick with 4 benches of coal aggregating 1.70 of coal, while in another part it is 2.43 meters thick and in 6 benches, but the thickness of coal is practically the same, 1.72 meters. The lower

[18] M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in der Ländern der ungarischen Kröne," Budapest, 1878, pp. 174, 176–179, 197, 198.

bed averages about 2 meters. Sometimes it is without partings but at others it is broken by two, 20 to 50 centimeters thick. Occasionally, one of the other beds is thick enough for mining, but in all cases the thickness shows much variation. The coal is of very fair quality; in the Barod area, moisture is from 8.2 to 10.4 per cent. and the ash is from 7.1 to 15.7 per cent.

In the Lower as well as in the Upper Cretaceous, coal seams accumulated on border areas, where the sediments show proximity to land. The character of the deposits, the lens-shaped coal seams and the fresh-water fauna associated with them seem to justify the suggestion that the coal was formed in swamps on great irregular river plains. For the most part, these had a comparatively brief existence and were subject to frequent floods carrying muddy water.

Australasia.

Molengraaff[14] reports that he saw thin seams of coal at various horizons in the Cretaceous along several rivers in central Borneo. These are without economic importance. The associated sandstones frequently contain grains of coal.

Coal is present in the Cretaceous of eastern Australia, though very rarely in economic quantity. As the conditions appear to be much the same throughout, it suffices to consider the phenomena in Queensland as described by Jack.[15] Cretaceous deposits cover a great part of that province, where they are divided into the Upper or Desert Sandstone and the Lower or Rolling Downs formation.

The Desert Sandstone formation, now remaining in barely one twentieth of its original area, consists mostly of thin flags, whose surfaces are covered with a network of raised lines, crossing each other at all angles, which clearly represent filled sun cracks. The same sands show tracks and burrows as well as indeterminate remains of plants. Cross-bedding is quite characteristic of the thicker layers. Pebbly deposits occur occasionally and, at one locality, Gibb saw an angular quartzose grit which passed into brecciated

[14] G. A. F. Molengraaff, "Geological Explorations in Central Borneo," Eng. ed., Leyden, 1902, pp. 202, 217, 241, 250, 277, 318.

[15] R. L. Jack and R. E. Etheridge, Jr., "Geology and Palæontology of Queensland," Brisbane, 1892, pp. 397–403, 511–536, 551, 558.

conglomerate. Silicified stems of trees and of bamboo-like plants were observed in many beds. On top of a small table-land in western Queensland, H. Y. L. Brown discovered a grove of fossil stumps standing erect. Thirteen are large, the greatest diameter being 4 feet and the usual height is 4 feet 6 inches. Many of the stumps are hollow and fragments lie in all directions. "The matrix having been denuded, they stand as evidence of how trees have degenerated in size in this part of the country since Cretaceous times."

The features of this formation throughout are those of a vast flood plain, subject to frequent overflow and to frequent changes in direction of drainage. As one should expect, the coal deposits of the Desert Sandstone are lenses of moderate extent and commercially unimportant. Within the Cooktown region, seams were seen 6 and 15 inches thick; the bottom of the latter is crowded with quartz granules. The coal is worthless; four samples from the Cooktown region gave 9.65, 19.02, 30.20 and 36.53 per cent. of ash. The coals vary from semi-bituminous to high-grade bituminous, though in the description of this region, no reason for this difference appears. Pellets of coal were seen frequently in rocks associated with the coal.

The Rolling Downs formation is mostly marine, with intercalated deposits, which may be of fresh-water origin. The higher rocks on the Upper Flinders River contain bands of ferruginous sandstone with markings which are suggestive of reptilian footprints. Farther up the river are thick-bedded sandstones, with grits, pebbly grits and conglomerates. These hold coal seams, one of which is in five benches with 22 inches of coal and a total thickness of 4 feet 9 inches. Other but thinner seams were seen in this neighborhood. The coal is very good and cakes. Near Winton, borings have passed through some seams of coal, but all are thin, none exceeding 2 feet, and the coal in the several seams varies, the ash being from 4.58 to 20.34 per cent. Some seams, 3 feet thick, have been observed elsewhere in Queensland, but they are merely lenses, marking sites of swamps occupying depressions in sandy river plains.

Identifiable remains of plants are rare in the Queensland Cre-

taceous, only two forms having been recognized. One of them belongs to *Glossopteris* and was found in the Desert Sandstone. Etheridge cannot distinguish it from *G. browniana* and *G. ampla,* which abound in the Permo-carboniferous of Queensland and New South Wales. The important coal deposits of New Zealand, in the lower part of the Cretaceo-Tertiary, occupy some extensive areas in the South Island and a less important area in the North Island. The South Island was studied in detail long ago by Hector[16] and his associates. Hector examined Nelson district, the northern part of the island. The coal-bearing rocks at the Collingwood mine, in the extreme north, rest on 105 feet of conglomerate and are 250 feet thick. They are mostly thick-bedded clayey sandstones with interbedded carbonaceous shales, which have 6 coal seams, from 1 to 4 feet thick. But the coal is broken badly by partings. On the Ngakawau River there is a seam, 16 feet thick and yielding good caking coal, which burns freely with a sooty flame. In the lower canyon of Buller River, he saw a bed of compact brown coal, at least 16 feet thick, underlying brown micaceous sandstone and overlying a conglomerate or breccia of great thickness, which has a few thin seams of coal. The thick seam, which has much fossil resin, varies in composition; samples from different parts of the bed have from 33.45 to 46.85 per cent. of volatile combustible matter in the pure coal. The ash in raw coal is about 7 per cent. A seam, 20 feet thick, is mined on a branch of Buller River; its ash is remarkably low, varying from 0.98 to 1.19 per cent. The coal in some parts of the seam is compact, with bright luster and splintery fracture, but in others it is dull, with fracture like that of brown coal. and resembles jet.

In the Grey River area, the southwest corner of the district, the basal rocks are conglomerate and breccia, succeeded by 200 to 800 feet of sandstones, grits and shales with beds of anhydrous caking coal. Above these is a non-persistent conglomerate. Where this last is absent, the sandstones pass gradually into sandy clays with marine fossils and nodular clay iron-stone. Immediately below these marine beds and resting on the conglomerate or, in its absence,

[16] J. Hector, "Geological Survey of New Zealand," 1872, pp. 129–141, 158–165.

on the sandstones, is a seam of inferior coal, the "upper bed," which is a pitch coal, containing much resin and little constitutional water. The thick bed on Grey River, 16 feet, contains 64 to 68 per cent. of fixed carbon, while another seam, on the coast, has but 38.55 per cent. Hector described the latter as a very superior pitch coal, but its chemical composition suggests cannel; and it was recognized as such by Campbell,[17] who notes its variations in thickness. Within its small area, he saw it 4, 6, 16, 4, and 2 feet. At the border, it thins away to nothing. Cannel is the prevailing type in this bed. Another bed, resembling splint, contains pebbles of sandstone.

A more detailed study of the Buller Coal Field was made by Cox and Denniston.[18] At Coalbrookdale in Waimangawa Basin, Cox saw two coal seams, 5 and 18 feet thick, separated by 34 feet of sandstone; but at a short distance away they become 6 inches and 11 feet 6 inches. The upper bed quickly disappears but the lower one thickens northwardly until it becomes 40 feet, beyond which it decreases. Still farther north, beginning at Mount Frederick in the Ngakawau Basin, this lower seam is 5, 25, 37, 40 and, at center of the basin, 53 feet; thence it thins away in all directions, the last measurement being 6 inches. Other beds show similar variations. Southwardly from the Waimangawa Basin, the conditions are the same. Descending a stream from Mount Williams, Cox saw an outcrop of shale; at a little distance beyond, this became a coal seam, 3 feet thick, but worthless because of numerous shale bands. Followed southwestwardly, this, the lower coal seam of other basins, became 3, 8, 20, 40, 20, 20, and 25 feet. But southward from the last measurement the seam thinned away until no trace of it could be found.

Denniston's descriptions and his numerous sections show the lens form of the coal seams, thickest at center and thinning away to disappearance toward the margins of the basins. He notes that coal of the lower seam is not the same throughout a basin. In one area the upper portion is tender but the lower is hard; in another, the prevailing type is splint or cannel, hard, compact, jetlike, burning

[17] W. D. Campbell, New Zealand Geol. Survey, Reps. for 1876–7, pp. 31–40.

[18] S. H. Cox, N. Z. Geol. Survey, Reps. for 1874–6, pp. 17–29, 106–119; R. Denniston, the same, pp. 121–171.

with a candlelike flame and showing little tendency to cake. The descriptions by Cox and Denniston make clear that the basins were contemporaneous but not connected.

The district of Canterbury, embracing the middle eastern part of the island, was examined by Haast.[19] The Malvern Hills area, about 30 miles west from Christchurch and embracing not far from 180 square miles, exhibits his Great Brown Coal Formation, which, in the Table of Formations of 1879, is placed at base of the Cretaceo-Tertiary. The coal seams are numerous, usually thin and always variable. Occasionally, nodules of retinite are numerous. The intervening rocks show great irregularity in structure. Sandstones have abundance of tree trunks, whose thick bark has been replaced with clay ironstone, while the interior tissue has been replaced with "woodstone" or filled with black shaly material.

The extensive district of Otago, embracing the southern part of the island, was examined by Haast, McKay and Hutton.[20] In Haast's area the lower part of the column has near the base a mass composed of subangular fragments of schists and containing irregular seams of coal, 6 to 15 inches thick. Higher up, the rock becomes a conglomerate with well-rounded pebbles of quartz. The thin-bedded sandstones and shales following this conglomerate have only thin seams, but in the upper part of the column there are beds of conglomerate separated by thinner shales and sandstones, which hold important coal seams.

Coals are mined on Green Island. Near one of the shafts, McKay saw a bed of fossilized roots "sticking in an old soil, just as they grew." At another locality, a workable coal seam underlies beds containing *Belemnitella*.

According to Hutton, the area of Cretaceous coals is small in Otago. The most important field is near Shag River, where there are at least 6 workable seams, yielding the best of brown coal. The seams are thin in the Mount Hamilton field, rarely exceeding 10 inches, but the coal is bituminous. The highest sandstone there contains at base an angular block of sandstone, 8 by 3 feet, resting on

[19] J. Haast, N. Z. Geol. Reps. for 1871–2, pp. 1–88.

[20] J. Haast, Reps. for 1871–2, pp. 148–153; A. McKay, Reps. for 1873–4, pp. 59, 60; F. Hutton, "Geology of Otago," Dunedin, 1875, pp. 44, 100–103.

a thin seam of coal. He conceived that it had been floated in, attached to the roots of a tree, "wherefore the coal beds are formed partly from driftwood."

The coals of New Zealand for the most part are lignitic or sub-bituminous, but no woody structure is mentioned by any observer.

Greenland.

The existence of coal in the Cretaceous of western Greenland was made certain by the work of White and Schuchert[21] during 1897. Their observations were made chiefly on the Nugsuak Peninsula. The Komé or lower division, as exposed near Kook, consists of shaly or laminated sandstones with thin beds of dark shale containing much carbonaceous matter, so abundant at times as to make the shale combustible, but not enough to justify one in calling it coal or lignite. The whole succession is so irregular that sections are not comparable. The plants are conifers, cycads and ferns with some indeterminate leaves of dicotyledons. Near Ugarartorsuak, all divisions of the Cretaceous were examined. The Komé, in a section of 270 feet, has 20 feet of "thin coals with shaly partings and 2 bands of carbonaceous shale." Another section of about 305 feet, belonging to the Atane or middle division, has several beds of coaly shale, a coal seam, 1 foot 6 inches and a mass of "thin sandstones and coals," 10 feet. The flora differs from that of the Komé as, besides cycads, conifers and ferns, it has 8 species of dicotyledons. A third flora, in still higher beds, is related to the second and both seem to be related to the Upper Cretaceous. Dark beds with huge ferruginous concretions, have fossils of types characterizing the Montana of western United States.

A dark shale, 75 feet thick, seen near Ata on the southerly shore of the peninsula, has leaves and large fragments of tree trunks with an invertebrate fauna, which Stanton takes to be the same with that of the highest beds on the north shore and equivalent to Cenomanian. The highest division of the Cretaceous, Patoot of Heer, is exposed near Patoot, where the lowest beds are at 470 feet above the sea. The fossils are of Senonian age and some of the plants are

[21] D. White and C. Schuchert, "Cretaceous Series of the West Coast of Greenland," *Bull. Geol. Soc. Amer.*, Vol. 9, 1898, pp. 343–368.

allied to Laramie forms. The authors suggest that, at least in part, the Patoot may be a transition formation; no unconformity was observed between Cretaceous and Tertiary; all conditions indicate that sedimentation was continuous. Near Patoot, at 1,170 feet above the base of this division, there are occasional bands, ferruginous, containing ferns, conifers, and dicotyledons, with erect stumps and abundance of silicified wood.

North America.

Cretaceous deposits are present on the Atlantic and the northern Gulf coasts of the United States, but they contain no coal and the occurrences of lignite have interest only for the paleobotanist. The important area is in the west-central region, where the deposits originally extended from the 95th meridian westward for not far from 1,000 miles, and from Lat. 25° in Mexico northward for not less than 2,100 miles, in all not less than 2,000,000 square miles. These figures are merely approximations and the area of greatest extent may have been considerably larger. The continuity of these deposits was destroyed by post-Cretaceous erosion, following the Rocky-Mountain revolution.

Belief that Cretaceous deposits were practically continuous throughout this vast area is of comparatively recent data. The prevalent conception until within little more than 20 years, was that the Rocky Mountains had existed during Cretaceous time. There seems to be little room for doubting the general accuracy of conclusions that those mountains mark lines of successive foldings but proof of their existence as elevated areas is wanting. Willis[22] thought that the earliest Cretaceous deposits of his district were laid down on a surface of Carboniferous and Algonkian rocks, which was a plane, primarily a peneplain and afterwards a surface of marine planation. The first period of compression may not have begun until after close of the Cretaceous. Incidental reference to the conditions indicates similar conception on the part of some later observers; but the first clear analysis of the evidence, known to the writer, is that by Lee,[23] who has discussed the phenomena observed by him-

[22] B. Willis, "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 338, 339.

[23] W. T. Lee, U. S. Geol. Survey, Prof. Paper, 95-*C*, 1915, pp. 56–58.

self and others in New Mexico and Colorado. He recognizes peneplanation in the southern Rocky-Mountain region prior to the beginning of the Upper Cretaceous. The evidence all indicates that the interior continental sea extended from Utah and Arizona eastward over the present site of the Rocky Mountains.

The source of sediments was at the south and west, as appears from discussions by Lee, Stone and Calvert and Stebinger,[24] as well as from sections by many other observers. The coarser materials are in the southern and western parts of the area, while, toward the east, land and border-land conditions disappear, so that the rocks become shales with more or less of limestone. But toward the close of the Cretaceous, land and shore deposits extended far east, indicating perhaps a long period of comparative stability prior to the great mountain-making period of the Tertiary. The vast area, reaching in some places almost to the Mississippi, was apparently at first almost a peneplain, over which the early Cretaceous sea advanced to the western border.

During and after the Rocky-Mountain revolution, erosion was so energetic that, in New Mexico, Arizona, Utah and Colorado, the Cretaceous was broken into isolated "fields" or "basins," separated in many cases by ranges showing Archean rocks at thousands of feet above the general altitude of the region. But this greatly disturbed area becomes narrower toward the north, so that, in much of Wyoming, the continuity is broken only by comparatively short ridges around which the Cretaceous rocks outcrop. Still farther north, the undulations in by far the greater part of the area are gentle and sedimentation appears to have been continuous into the Tertiary; the greatly disturbed region on the western side trends toward the northwest and becomes very narrow. During the Cretaceous, deposition was practically continuous, there being only local unconformities, so small vertically and horizontally as to be surprising, in view of the vast area under consideration. There are, however, great variations in thickness which seem to be due to differential subsidence. The conditions favoring accumulation of coal were repeated many times in the region of coarser sediments and

[24] W. T. Lee, Prof. Paper, 95-*C*; R. W. Stone and W. R. Calvert, *Econ. Geol.*, Vol. V., 1910; E. Stebinger, Prof. Paper, 90-*G*, 1914.

the formation of offshore deposits was marked by an assemblage of fossils which survived the changing conditions and reappeared at several horizons.

It was to be expected that during the period of reconnaissance surveys, coal groups belonging near the base of the Upper Cretaceous should be correlated with others elsewhere, which are in highest formations of the series. One familiar with the facts, as now understood, is not astonished by the contradictions, when he considers the conditions under which the earlier work was done. During recent years, detailed studies by geologists of the National surveys of the United States and Canada have done so much toward removal of uncertainties, that it is possible to present a comparative table of formations, which, as a generalization, is near enough to the truth for purposes of this study.[25]

The first systematic classification of the western Cretaceous was presented by Hall and Meek.[26] Hall had financed an expedition to make collections between the Missouri River and the Mauvaises Terres, Meek being in charge. The succession, based chiefly on Meek's observations, is

Eocene, Tertiary Formation, clays and sandstone, etc., containing remains of mammalia, 250 feet.

Cretaceous Formation,

5. Arenaceous clay, passing into argillaceous sandstone, 80 feet.
4. Plastic clay, with calcareous concretions containing numerous fossils. This is the principal fossiliferous bed of the Cretaceous on the upper Missouri, 250 to 300 feet.
3. Calcareous marl, containing *Ostrea congesta,* scales of fish, etc., 100 to 150 feet.

[25] The writer would not neglect acknowledgment of his great indebtedness to the writings of W. T. Lee, T. W. Stanton, N. H. Darton, F. H. Knowlton, E. Stebinger, R. W. Stone and W. R. Calvert, of the United States Geological Survey and to those by D. B. Dowling, of the Geological Survey of Canada. Several of these students have been unreserved in communicating unpublished material; but they must not be held responsible for conclusions offered by the writer, some of which may appear to them far from correct.

[26] James Hall and F. B. Meek, "Descriptions of New Species of Fossils, from the Cretaceous Formation of Nebraska," *Mem. Amer. Acad. Arts and Sci.,* 1856, p. 405.

2. Clay containing few fossils, 80 feet.

1. Sandstone and clay, 90 feet.

The thicknesses were purely tentative, as the party, owing to unexpected complications, were compelled to make a remarkably rapid reconnaissance. Several years later, Meek and Hayden published an amplified section, based on examinations and collections made by Hayden while associated with the Raynolds expedition.[27] In this memoir, geographical names were applied to the several formations, Fox Hills beds, No. 5; Fort Pierre group, No. 4; Niobrara division, No. 3; Fort Benton group, No. 2; Dakota group, No. 1.

The Fort Union or Great Lignite Group, which overlies the Fox Hills, was placed in the Tertiary. This grouping was based on the fossil remains, not on the lithological features and it was applicable apparently throughout the eastern part of the Cretaceous region. In the early 70's discussion arose respecting the relations of some coal deposits which had been referred to the Fort Union; the term "Laramie" was introduced for the deposits in dispute, to be employed without committing the writer to either Tertiary or Cretaceous age. Studies in more recent years made necessary a change at the base of the column. Darton's examination of the Black Hills in northeastern Wyoming showed that the Dakota is complex, that the middle and lower portions carry Lower Cretaceous forms, while the upper portion belongs to the Upper Cretaceous. Some years afterward, the same author, and later Lee and Stanton, discovered fossils with similar relation in the same beds within New Mexico. These lower beds were correlated with the Kootenai of Canada.

When, however, an attempt was made to apply the Missouri River section to the country west from the 106th meridian, serious difficulty was encountered. The character of the deposits was wholly different. The matter was complicated by the fact that the earlier explorers did not recognize that the great erosion was due to post-Cretaceous elevation of the mountains and by the other fact that they did not know that a grouping of fossils, resembling that of the Fox Hills, occurs in that region low down in the column. In

[27] F. B. Meek and F. V. Hayden, *Proc. Acad. Nat. Sci.*, Philadelphia, 1861, citations from pp. 419, 432.

the later work, exigencies made necessary the study of economically important districts and the temporary ignoring of intervening districts. The column was divided for descriptive purposes, largely on the basis of lithology and local names were introduced, which were utilized in other districts, but not always in the same sense. At an early date, the difficulty in determining boundaries of formations at the west was recognized; the Fox Hills and the Pierre were combined as the Montana and the Niobrara and Fort Benton as the Colorado. In this study, the Meek and Hayden classification is employed as it is based on palæontological ground and enables one to recognize changes in physical geography. As modified by later studies it is

Laramie
Montana { Fox Hills, Pierre
Colorado { Niobrara, Benton
Dakota
Kootenai.

Each of the several formations is coal-bearing in areas of greater or less extent, but barren or nearly so in others of greater extent. They will be described in the order of age. Literature dealing with the coals of the western Cretaceous is voluminous, but it consists largely of preliminary studies with land classification as the object. Much of the region is very sparsely settled, as it is agriculturally arid, and systematic mining is confined to narrow strips along the railways. For the most part, explorers must depend on natural exposures, which are indefinite. At the same time, one cannot refrain from grateful acknowledgment of the skill exhibited by not a few of the observers, for the mass of information is so great as to prove an embarrassment in preparation of this review.

The Laramie, Lance, Edmonton.

The post-Cretaceous erosion spared only scattered areas of Laramie in the southern districts, but farther north, where the region of orogenic disturbance was restricted more and more to the far

western border and deposition was apparently continuous in the plains, Laramie covers or underlies great spaces.

In the present state of knowledge, one may not assert or deny the existence of Laramie beds in the important Trinidad-Raton field of Colorado and New Mexico. Lee's discovery of an unconformity by erosion in the mass, formerly regarded as Laramie, has made the relations of the Raton formation, that above the unconformity, somewhat uncertain. The plant remains appear to have Tertiary affinities. The report by Lee and Knowlton on this field is still unpublished. It would appear that the Laramie is present in the isolated coal field on the Arkansas River, near Canyon City, Colorado. Stevenson[28] in his first report referred all the coals of this field to the Laramie; but at a later date, he restricted that formation to the upper part, 880 feet, which is in accord with the later measurement by Washburne. This later observer obtained plant remains which show that the rocks are equivalent to a part, at least, of the Laramie as recognized farther north in the Denver Basin. The coal seams are irregular in occurrence and appear to be mere lenses. The sandstones and shales are so variable that vertical sections, less than 100 yards apart, are wholly dissimilar.

The Denver Basin extends along the eastern foot of the Front Ranges almost to the northern boundary of Colorado. The Mesozoic deposits were studied by Eldridge.[29] The Laramie, 600 to 1,200 feet thick, consists mostly of sandstones in the lower, but of clays in the upper part. Coal seams in the higher beds are thinner and much more irregular than those in the lower division, which is about 200 feet thick. *Ostrea glabra,* according to Eldridge, occurs in the lower division, so that in the writer's opinion this sandstone is closely allied to the Fox Hills, to which it is lithologically similar. Sections throughout show great variation in the rocks as well as in the coal seams, so that in any district, strict correlation of coals in different mines is possible only where the workings are continuous. The coal seams of the lower division are from 3 to 14 feet thick. A seam,

[28] J. J. Stevenson, U. S. Expl. W. of 100th Mer., Vol. III., 1875, pp. 393–397; *Proc. Amer. Phil. Soc.,* Vol. XIX., 1881, pp. 505–521; C. W. Washburne, U. S. Geol. Survey, Bull. 381, 1910, pp. 341–378.

[29] S. F. Emmons, W. Cross, G. H. Eldridge, U. S. Geol. Survey, Monog. 27, 1896, pp. 51–74, 323–369.

mined in the Lafayette district, is 14 feet thick at the outcrop; but within 500 feet a parting appears, which increases northwardly to 10 and at length to 25 feet. The splits remain good in this direction, but southwardly, as the parting increases, the lower split is broken more and more by slates until it becomes worthless. The coal in some seams is not the same throughout; one bench may be hard, another soft. In one bed, the upper bench yields softer coal than the lower, which is complex, consisting of: Bright coal with conchoidal fracture, 6 inches; crushed coal, 6 inches; fibrous coal, 36 inches. The coal of the Denver Basin often has woody structure and contains silicified tree trunks, knots and branches. It is resinous at many places.

D. White[80] states that, while the coals of this Basin are relatively persistent, they vary greatly in thickness. The topography of the floor reveals shallow "swales" or ponds, occasionally extending a mile or more, in which the coal is thicker. The floor at Lafayette is a bluish sandy underclay, containing numerous roots in place, probably an old swamp soil; resting on this is a bed, 8 to 30 inches thick, of dark carbonaceous clay, or lignitic mud, filled with flattened stems, lying in all directions, some of them very large and many are much compressed. The roof is sandstone with no transition from the coal.

In general, the coal is essentially xyloid, there being apparently more wood than in the lignite of Hoyt and Rockdale in Texas, though less than in that of Wilton and Lehigh in South Dakota—all of them Eocene. The quantity of jetified wood is large but the branches and limbs are compressed to thin lenses. Mineral charcoal is abundant, often in large fragments. A log was seen, 14 by 5 inches in section, jetified in the interior, while the outer portion had become mineral charcoal; but another specimen was hollow, containing mineral charcoal in the interior, while the outer portion was jetified. Irregular lumps of yellow resin are numerous and at times this material has been squeezed into the joints.

The coal at Marshall, 10 miles from Lafayette, is at the same horizon, being regarded as one of the splits of the main Lafayette seam. Silicified wood is abundant and well-preserved, showing

[80] D. White, "The Origin of Coal," Bur. of Mines, Bull. 38, 1913, pp. 20–23.

grain and rings distinctly. The lower part of the bed is more conchoidal, less xyloid and has higher percentage of fixed carbon than the upper, suggesting, as White says, that it represents a more matured peat. He could obtain no data respecting the floor of this bed, but roots were found under two coal seams in a railway cut, the sandy floor of one being undoubtedly an old soil.

Thiessen's[81] microscopic study of the Lafayette and Marshall coals proved that, generally speaking, the type of vegetation and the conditions during accumulation must have been very similar to those during the Eocene in Montana and Dakota, though the proportion of woody materials is somewhat less and the compression is greater. The resin is darker than that of the Dakota lignite. The débris contains the reticulated bodies observed in the pith of certain fossil wood and present in all Tertiary and Cretaceous coals which Thiessen has examined. Fungal hyphæ and spores are abundant, the former especially in material of herbaceous origin. Spores and pollen exines compose not more than 5 to 10 per cent. of the mass.

A notable area of Laramie has escaped erosion in the northern part of the San Juan Basin within New Mexico and Colorado. On the eastern outcrop, according to Gardner,[82] coal seams are very thin or are wanting; but on the western outcrop, Shaler saw along the Rio Chaco several coal seams which occasionally become workable, with a maximum thickness of 3 to 6 feet. Farther north, on the San Juan and Plata Rivers, he saw the Carbonero seam with maximum thickness of 50 feet; but it is variable, for at one locality it is little more than 6 feet and is broken by three partings. Beyond the Colorado line, near Carbon Junction, the thickness increases to about 100 feet; the partings are very numerous, but there are some bands of clean coal, 4 to 5 feet thick. The bed divides toward the west; at 3 miles southeast from Durango, Shaler saw three seams, 7, 30 and 15 feet, in a vertical space of less than 200 feet, which he believes to be splits of the Carbonero.

Apparently no part of the Laramie has escaped erosion in the great Uinta Basin of northwestern Colorado; or, at least, if any still remain, its rocks are so similar to those of the Pierre that no

[81] R. Thiessen, Bur. of Mines, Bull. 38, 1913, pp. 241–243.

[82] J. H. Gardner, Bull. 341, 1909, p. 388; M. K. Shaler, Bull. 316, Pt. 2, 1907, pp. 385, 386, 395, 396, 400, 404.

separation can be made. The coal deposits of this region were referred to the Laramie by the earlier observers; the later observers have proved that they in the Pierre.

Laramie coals are important in the Green River Basin of southwestern Wyoming. The Cretaceous section in the outlying coal field of Coalville in northeastern Utah has on top 2,500 feet of mostly sandy beds, with leaves and fresh-water shells, but no coal. This rests on 1,650 feet of sandy beds with marine fossils.[33] At about 30 miles northeast, one reaches the Laramie area of Uinta County, Wyoming, where the Laramie, according to Knight and Veatch,[34] is more than 5,000 feet thick in the southern part of the county. There, as in the Coalville field, one is near the western border of deposition and the formations are thick. Schultz found only 2,800 feet remaining in the northern part of the county. The lower portion of the column for several hundred feet contains marine fossils and it must be referred to the Fox Hills; but Laramie leaves are abundant in the higher deposits. The Tertiary coals of Evanston overlie the Laramie uncomformably. Coal seams are numerous in the Laramie and at times they are workable, but the thicker seams of the Tertiary render them unimportant.

The Rock Springs coal field in Sweetwater County is about 50 miles farther east, only Tertiary deposits being at the surface in the intervening space. Schultz[35] gives the thickness of Laramie as 3,900 to 1,500 feet, the variation being due to extent of erosion. The lower part of the section is clearly Fox Hills; the Laramie beds are sands and clays with little coal. The marine sandy beds persist eastwardly and the Laramie rocks retain their features, finer in grain, more argillaceous and without important coal beds. In southern Carbon County, Ball and Stebinger[36] find an extreme thickness of 4,000 feet, but the formation thins away southward. The lower part of the column for about 400 feet must be assigned to the

[33] C. H. Wegemann, Bull. 581-*E*, 1915, p. 161.

[34] W. C. Knight, "Southern Uinta County, Wyoming," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542–544; A. C. Veatch, Bull. 285, 1906, p. 333; A. R. Schultz, Bull. 316, 1907, p. 217.

[35] A. R. Schultz, Bull. 341, 1909, p. 259; Bull. 381, 1910, pp. 223, 227.

[36] M. W. Ball and E. Stebinger, Bull. 341, 246, 253; Bull. 381, pp. 190, 193, 204.

Fox Hills. The coal seams are irregular except in the northern part of the district, where beds were seen, 8, 6 and 4 feet thick. Whether these belong to Fox Hills or to Laramie cannot be determined from the sections. In the southern portion of the basin, within Colorado, the Laramie is 900 feet thick according to Fenneman[87] and Gale, consisting of alternating sandstones and shales, with indications of 20 lignite seams distributed irregularly in the upper two thirds. The writer regards the lower third as belonging to Fox Hills and thinks that the thick coal seam near Craig, 8 feet, is in that formation.

Northward from the Green River Basin, areas of Laramie are comparatively unimportant. On the west side of the Bighorn basin, lenticular coal beds were seen by Woodruff at many places in the lower part of the formation. Washburne found 150 to 700 feet between the Eocene and the Pierre formation, massive sandstones and shales; in this, taken to be Laramie, there are thin and variable coal beds. The only workable seam is near Garland where 4 feet of clean coal had been worked; but the seam quickly breaks up in all directions and becomes worthless. The Buffalo coal field, east from Bighorn Mountains, shows great irregularity in deposition during the Laramie, but the coal seams, though varying in thickness and quality, can be traced for considerable distances. In the Sussex coal field, 30 miles farther south, Wegemann found the Lance formation, 3,200 feet thick and resting on the Fox Hills. The coals are unimportant except in two localities, where seams occasionally become workable. Wegemann's descriptions seem to make clear that the coals are mere lenses and the better coal is in the middle portion of the lens. Winchester measured about 2,450 feet of Lance beds in the Lost Spring coal field, which is on the western border of the great Tertiary lignite area. There are traces of the coals seen farther west, but only carbonaceous shale was found. The Fox Hills, Lance and Fort Union appear to be conformable in this region. The highest rocks in the Black Hills area of northeastern Wyoming are sandstones, shales and lignites, in all about 2,500 feet, as determined by Darton. That student hesitated to identify these beds as Laramie, because it was not possible to determine whether or not they are conformable to the underlying Fox

[87] N. M. Fenneman and H. S. Gale, Bull. 285, 1906, p. 288.

Hills. The relations of the Lance formation have been subject for much discussion; the testimony of plant and animal remains is contradictory. In no inconsiderable area, the Lance is conformable to the Fox Hills. Winchester in a recent note, summarizing results obtained by himself and his assistants, in eastern Wyoming, states that Lance overlies Fox Hills. It is subdivided into three members; a lower undifferentiated portion, 425 feet thick; a middle, lignite-bearing portion, the Ludlow, at least 350 feet; and an upper marine member, the Cannonball, 225 feet. The marine fauna of the Cannonball is very similar to but not identical with that of the Fox Hills, while flora of the Ludlow cannot be differentiated from that of the Tertiary Fort Union.[38]

The eastern half of Montana is a rolling plain covered with Tertiary and later deposits, the mountains of states at the south having disappeared. Anticlinals have brought up the highest members of the Cretaceous. The Lance, taken by the writer as the eastern extension of the Laramie, has at base the Colgate sandstone, which is 90 to 175 feet thick and contains no coal except at one locality, where Hance saw a lens only a few hundred yards long. The upper part of the Lance, about 500 feet, has variable seams of lignitic coal, but all are lenticular. Some observers note great irregularity in the deposits, which appear to be fresh-water throughout.[39]

West from the 109th meridian, one approaches the mountain region and finds the whole Cretaceous exposed. In northern Fergus County, the Lance appears to be present, but the relations of the beds are not altogether clear. Near the Crazy Mountains in Meagher County, Stone found 1,200 to 2,800 feet of shales and sandstones, which he places in the Laramie; but the Lennep sandstone, at the base, 200 to 400 feet thick, is known now to be Fox Hills. Lenses of coal, a few inches thick and of insignificant horizontal extent, are present in the Laramie. Not far westward from this district shore conditions prevail and a continuous formation,

[38] E. G. Woodruff, Bull. 341, 1909, pp. 202, 205; Bull. 381, p. 173; C. W. Washburne, Bull. 341, pp. 167, 169, 181; C. H. Wegemann, Bull. 471-*F*, 1912, pp. 26, 30; D. E. Winchester, Bull. 471-*F*, p. 58; *Journ. Wash. Acad. Sci.*, Vol. VII., 1917, p. 36; N. H. Darton, Prof. Paper 65, 1909, p. 58.

[39] W. R. Calvert, C. F. Bowen, F. A. Herald, J. H. Hance, Bull. 471-*D*, 1912, pp. 13, 21, 48, 49, 91.

the Livingston, occupies the whole interval from near the base of the Pierre to the lower portion of the Fort Union.[40]

In Teton County, on the Canadian border and near the western boundary of the Cretaceous, Stebinger saw 980 feet of clay, clay shales soft gray to greenish gray cross-bedded and rippled sandstones with coal seams and some lenticular limestones. Apparently, the succession from Lower Cretaceous to the top of the Eocene is conformable throughout. This mass, placed by Stebinger at top of the Cretaceous column, is shown by tracing to be the St. Mary formation of Dawson in Alberta. Its sandstones contain fossil wood. Coal seams occur at top and near the bottom, but they are too thin and uncertain to be of economic importance. The persistence of a coal horizon near the base proved, as Stebinger observes, the existence of widespread though transient coal-forming conditions soon after deposition of the great Horsethief (Fox Hills) sandstone. The coal seams improve near the Canadian border.[41]

Passing over into Canada, Dawson in southeastern Alberta placed a great mass of deposits in the Laramie, but later studies have made evident that only the lower division should be referred to that formation. This, the St. Mary beds, is, at least in part, the same with the Edmonton of Dowling and with the Lance in Wyoming and Montana. The formation, about 2,800 feet thick, is of freshwater origin except at the base and in its upper portion has sandstones which are cross-bedded, rippled and with worm borings.[42] Dowling[43] measured about 3,000 feet on Oldman River, mostly sandstone with sandy shales and some thin coals at the base. In the Sheep River district, two seams were seen near the Foothills, but farther east on Sheep River there is only one. Tyrrell[44] studied a large area in eastern Alberta between the Red Deer and North Saskatchewan Rivers. At the south near Red Deer River, he saw two important coal seams near the top of the formation, each about

[40] R. W. Stone, Bull. 341, pp. 82, 84; R. W. Stone and W. R. Calvert, *Econ. Geol.*, Vol. V., 1910, pp. 551–557, 652–669, 741–764.

[41] E. Stebinger, Bull. 621-*K*, 1916, pp. 124, 127, 128, 145.

[42] G. M. Dawson, Geol. Survey of Canada, Reps. Prog. 1882–83–84, Part *C*, pp. 36–72.

[43] D. B. Dowling, Summ. Reps. for 1903, pp. 142–149; the same, for 1914, p. 47.

[44] J. B. Tyrrell, Rep. Prog. for 1886, Part *E*, pp. 56, 60–63, 132.

10 feet thick; but he did not find them persistent. In the North Saskatchewan portion of the area, the important coal is also near the top of the formation. The chief seam was seen first near Wintering Hills as a bed of carbonaceous shale; but farther north it becomes coal and increases steadily until it becomes 25 feet thick. Several seams were seen in the lower portion of the formation, but the most persistent horizon is about 160 feet above the Pierre. Cross-bedded sandstone was observed at many localities.

About twenty-five years later, when the region had been opened up, Dowling[45] reported upon the Edmonton District, a portion of the area studied by Tyrrell. There he found about 700 feet of Laramie (Edmonton, St. Mary), a succession of shales and sands, too often merely clays and sands, a brackish-water formation between the marine Pierre and the fresh-water Pashkapoo of the Tertiary. It is rich in coal seams, which increase from south to north. The important coal horizon is near the top of the formation and it has been followed from the Red Deer to the Pembina River, becoming thicker toward the north and northwest. Three seams were seen on the Pembina, of which the highest is 26 feet thick; on the north Saskatchewan, a seam, belonging to the same coal group in the upper part of the formation, is 25 feet. Below the middle of the formation, Dowling saw another coal group; some of its seams are lenses of moderate extent, while others have been traced by borings under a considerable area; but they vary greatly in thickness and may be lenses. Dowling is evidently far from certain that the main seam of the region is persistent.

McConnell[46] states that the Laramie in northern Alberta has numerous seams of inferior lignite and ironstone. Rose reporting on the Lance of southwestern Saskatchewan, refers to the formation as a transition from the marine Fox Hills to the fresh-water Fort Union. The rocks are slightly consolidated and the seams of lignite are unimportant.

[45] D. B. Dowling, Memoir 8-*E*, 1910, pp. 13, 16, 18, 27, 28.

[46] R. G. McConnell, Ann. Reps., Vol. VI.-*D*, 1893, p. 53; B. Rose, Summ. Reps. for 1914, pp. 64–67.

The Fox Hills, Lennep Sandstone, Horsethief Sandstone.

In this study the transition beds from the marine Pierre to the fresh-water Laramie are taken to be the Fox Hills. At very many localities, where the higher members of the Cretaceous have escaped erosion, this transition formation is a shore or offshore deposit of more or less coarse materials, with fossils, mostly marine but accompanied at times by brackish-water forms. Within some basins, coal seams of great economic importance are present, while in others, coal is wanting or in such small quantity as to possess only geological interest.

Reports on the San Juan Basin to which the writer has access, give no details sufficing to determine whether or not the Fox Hills is present in any considerable part of the Basin; but a section by J. H. Gardner, cited and discussed by Lee,[47] shows that it exists in the northern part. The Pictured Cliffs sandstone, 394 feet thick, mostly gray sandstone, contains marine fossils to the top. It underlies 79 feet of brackish to fresh-water beds, in which coal seams, 4 and 12 feet thick were seen at 4 and 57 feet from the base. Lee includes these in the "Laramie," as there appears to be uncertainty respecting the relations of some parts of the column. No coal has been reported from the Pictured Cliffs sandstone.

The existence of Fox Hills is equally uncertain in the Uinta Basin of western Colorado. Fox Hills conditions recurred at various horizons in the Pierre of this basin, as they did in central New Mexico, so that the earlier observers recognized both Fox Hills and Laramie in the Pierre beds. But there is no room for doubt that the formation exists in the southeast prong of the Colorado portion of the Green River Basin; for there Gale[48] found the basal sandstone of the "Laramie," resting on the Pierre, with a marine fauna. The thick coal bed at Craig apparently belongs in the Fox Hills. About 50 feet of this formation has escaped erosion in North Park, Colorado, where it rests on the great mass of Pierre shale. There Beekly obtained marine shells and the fucoid *Halymenites major* from this sandstone; but no coal is present.[49]

[47] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 587–591.
[48] H. S. Gale, Bull. 341, pp. 287, 295.
[49] A. L. Beekly, Bull. 596, 1915, p. 46.

The relations are sufficiently clear in the main portion of the Green River Basin with Wyoming. In Uinta County, the basal 200 feet of "Laramie" with alternating marine and land deposits includes among others the great Adaville-Lazeart coal seam, 10 to 84 feet thick; Veatch's brief summary of the coals gives no details respecting the accompanying rocks. Schultz found in the Rock Springs field of Sweetwater County a yellowish white sandstone at base of the "Laramie," overlain by sandstones, clays and coal beds; in some places fossils abound. The basal sandstone rests on the upper member of the Pierre. The coal of this Fox Hills is inferior and is no longer mined. Smith reports that in northeastern Carbon County, marine fossils are present up to 500 feet from the base of the "Laramie," which, he says, is a common condition in southern Wyoming and northern Colorado. Here as in other parts of the basin, a great sandstone is at the base. Coal is present in the Fox Hills, but the beds are unimportant, the thickest being only 18 inches. Veatch[50] separates the beds with marine fossils in east central Carbon from the Laramie and places the great white sandstone with its overlying beds in the Pierre. No occurrence of coal is noted. Ball and Stebinger in southern Carbon place the sandstone and the overlying beds in the Laramie, but state that marine fossils have been up to 400 feet above the sandstone. They give no details respecting the character of the beds and apparently they saw no coal.

The Raton-Trinidad coal field of New Mexico and Colorado is at the eastern foot of the Front Ranges. The earlier students regarded the coal-bearing rocks as conformable throughout and placed them in the Laramie. The numerous unconformities observed were thought to be merely local variations, characterizing deposits on the rudely level strand area. Lee, however, has proved that the irregularities are far greater than imagined by his predecessors and that a great unconformity by erosion separates the column into the Raton and Vermejo formations, the former most probably of Tertiary age. The Vermejo, resting on the Trinidad sandstone, is taken by the writer to be Fox Hills but Lee is inclined to regard it

[50] A. C. Veatch, Bull. 285, 1906, p. 333; Bull. 316, 1907, pp. 246, 248; E. E. Smith, Bull. 341, pp. 225, 228, 229; M. W. Ball and E. Stebinger, Bull. 341, pp. 246, 247; Bull. 381, 1910, p. 193.

as somewhat older. At the same time, in view of conditions farther north along the eastern foot of the Front Ranges, the writer feels compelled to abide by his opinion expressed 35 years ago, that in large part, at least, the rocks belong to the Fox Hills. The basal sandstone known now as the Trinidad sandstone (Halymenites sandstone of Stevenson), contains some marine fossils with great abundance of the fucoid, *Halymenites major;* the overlying beds, with extreme thickness of about 500 feet, are prevailingly sandstone with interbedded shales and coal seams. The rocks have fossil leaves, which are older than Laramie and a few marine fossils have been seen. The coal seams are numerous but are indefinite, varying so greatly in thickness and relative position that correlation, especially of the higher ones, is not possible. All are excessively variable in the New Mexico portion of the field, but some of them attain importance in modest areas and are mined extensively. In the northern or Colorado part of the field there are from one to 8 seams in the 250 feet above the Trinidad sandstone. This group is persistent and consists of lenses, which frequently are workable. Near Sopris, the seams "thicken and thin out characteristically," they are broken by partings and the coal is dirty. Near Trinidad, the coal is sometimes without a parting. The accompanying rocks are as variable as the coals. Near Pictou, 3 seams are mined. At the outcrop, the intervals are 15 and 30 feet; but at 2,500 feet in the mine, the upper and middle beds have united and the interval to the lower one is but 20 feet. The coal seams are not persistent and resin is found in the northern part of the field.

	I.	II.	III.	IV.	V.
Coal	4 ft. 0 in.	0 ft. 8 in.	0 ft. 10 in.	4 ft. 0 in.	4 ft. 0 in.
Bone or shale.	0 ft. ½ in.	7 ft. 0 in.	21 ft. 10 in.	24 ft. 0 in.	7 ft. 0 in.
Coal	3 ft. 4 in.	1 ft. 8 in.	3 ft. 0 in.	5 ft. 0 in.	0 ft. 8 in.
Parting	thin	0 ft. 2 in.	14 ft. 0 in.	13 ft. 0 in.	25 ft. 0 in.
Coal	2 ft. 1 in.	5 ft. 0 in.	6 ft. 0 in.	9 ft. 0 in.	0 ft. 3 in.
Clay or shale.	1 ft. 4 in.	0 ft. 4 in.	8 ft. 0 in.	12 ft. 0 in.	22 ft. 5 in.
Coal	0 ft. 10 in.	2 ft. 0 in.	1 ft. 0 in.	1 ft. 0 in.	blossom
Total	11 ft. 7 in.	16 ft. 10 in.	54 ft. 8 in.	68 ft. 0 in.	58 ft. 11 in.
Total of coal	10 ft. 0 in.	9 ft. 4 in.	10 ft. 10 in.	19 ft. 0 in.	4 ft. 11 in.

On the northern side of the Raton plateau, a sandstone at 70 feet above the Trinidad coal bed, contains many weather-beaten tree

trunks along with worm borings and impression-like *Halymenites*. The extreme instability of conditions on the sandy flats, where coal accumulated, is shown by variations in the Trinidad coal bed, mined at Engle and Starkville. Stevenson's measurements are given in the preceding table.

These measurements are all within 3 miles from the first and the position to the Trinidad sandstone precludes all probability of error in correlation. The Trinidad sandstone is practically without coal.[51]

Fox Hills conditions are distinct farther north on the Arkansas River in the Canyon City coal field. Stevenson visited this field in 1873, but the movements of the party, to which he was attached, were so rapid as to give opportunity only for errors. He visited it again in 1881 and Washburne examined it in detail during 1908. These observers recognized the Trinidad sandstone, from which Stevenson, in both visits, obtained *Halymenites*. The Vermejo formation is about 500 feet thick, including the basal sandstone and its uppermost member is a massive sandstone, 145 feet, containing abundant *Halymenites*. According to Washburne, this member, nearer the mountains, loses its marine fossils, is less massive, is cross-bedded and has all the characteristics of a fluviatile deposit.

The coal seams are numerous and some are important. One, resting on the Trinidad sandstone, is 3 ft. 4 inches thick with at times shale, at others, sandstone as the roof, the less thickness being under the sandstone. The shale is 0 to 7 feet thick, showing that the erosion followed deposition of the shale. Sandstone "rolls" were seen by Washburne in a bed about 275 feet above the Trinidad sandstone. These extend for long distances and the sandstone passes through the roof clay, often through the coal to the floor. These "rolls" have rounded bottom, curved sides and the trend is toward northeast throughout the mine. The current bedding in the "rolls" indicates a northeast flow for the streams. Resin occurs in the lowest coal seam.

Fox Hills has been recognized in the Denver Basin by Eldridge

[51] J. J. Stevenson, U. S. Geog. Expl. W. of 100th Mer., Vol. III., sppl., 1881, pp. 102 ff.; G. B. Richardson, Bull. 381, 1910, pp. 385, 386, 395, 411; W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, p. 611. It is unfortunate that Lee's elaborate report on the Raton coalfield is still unpublished.

and by Fenneman,[52] who assign to it a thickness of 800 to 1,200 feet. These observers recognized no coal in the Fox Hills, as they took the important coal seams of the basin to be Laramie. But Stevenson[53] saw coal in rocks of Fox Hills age at 5 miles southeast from Evans, about 40 miles north from Denver. From a sandstone overlying coal he obtained *Ammonites lobatus, Cardium speciosum, Mactra alta, Mactra warreniana, Lunatia moreauensis* and *Anchura*. The *Halymenites* is abundant.

The deposits in western Wyoming, which earlier observers termed Fox Hills, are known now to belong to the Pierre, but the formation is present in some areas. The "Laramie" in the northeastern part of the Bighorn Basin, 150 to 700 feet thick, is apparently Fox Hills. It is mostly a massive sandstone but contains some seams of coal, occasionally workable though of quality inferior to that from older formations. East from Bighorn Mountains, the Fox Hills was recognized in the Lost Spring field by Winchester, in the Sussex field by Wegemann and in the Black Hills by Darton, but no coal is reported from any locality, except one, where Wegemann saw a deposit of "unusual variability in thickness and quality."[54]

The Fox Hills is known in northwestern Montana as the Horsethief sandstone described by Stebinger, as the Lennep sandstone of Stone and Calvert in the central part of the state. Stebinger traced the Horsethief sandstone across the Canadian boundary and proved its continuity with the Fox Hills of Dawson. He describes the sandstone as 360 feet thick, buff, coarse, massive and much crossbedded in the upper half, but becoming slabby and more or less shaly toward the base. Usually the fauna is brackish, *Ostrea, Corbicula, Corbula,* and *Anomia,* but at some horizons it is marine of the litoral type, *Tancredia, Cardium* and *Mactra*. In his paper of 1914, he shows that the Horsethief sandstone was at one time continuous from the Teton district at eastern foot of the Rocky Mountains to

[52] G. H. Eldridge, Mon. 27, 1896, pp. 69, 72, 73; N. H. Fenneman, Bull. 265, 1905, p. 33.

[53] J. J. Stevenson, *Amer. Journ. Sci.,* Vol. XVII., 1879, pp. 369–372.

[54] C. W. Washburne, Bull. 341, p. 169; D. E. Winchester, Bull. 471-*F,* 1912, p. 58; C. H. Wegemann, the same, pp. 25, 32; N. H. Darton, Prof. Paper 65, 1909, p. 57.

the Black Hills on the Wyoming border. No coal, aside from some insignificant lenses, has been seen in this northern extension of the Fox Hills; and the conditions are the same in Alberta.[55]

The Pierre Formation.

Thus far the tracing has been comparatively simple. The Laramie and Fox Hills mark the closing portion of the Cretaceous and conditions appear to have been much the same in each throughout the whole region. But during the Pierre, conditions near the source of sediments were wholly different from those in the great area beyond. On the eastern side, the rocks are almost wholly shale and without coal, while on the western and southern sides there are great deposits of sandstone and sandy shale with, in some areas, important coal seams at several horizons. At the east, the fossils are marine but at the west and south there are marine and brackish as well as fresh-water horizons. The offshore and strand conditions, marking strife between advancing land and the sea, are evident from the recurrence of a fauna allied to that of the Fox Hills as well as of sections showing a succession like that of Fox Hills and Laramie, a gradual transition from marine to continental deposits. In the description of widely separated areas, local terms based on lithological features became necessary, but the resulting confusion has been removed by the labors of the students listed on an earlier page and the relations are now well understood, though in some areas there still remains uncertainty as to the planes of separation.

In Alberta, Montana and northern Wyoming the Pierre is divided into Lewis or Bearpaw shale, Judith River formation, Claggett shale and Eagle sandstone: the last, overlying shale. This order, descending, is distinct from the Bighorn Basin of Wyoming northward into Alberta, but, at a short distance westward, where one approaches the western limit of Cretaceous deposition, some modifications in nomenclature and grouping become necessary. Farther south in Wyoming, Colorado and New Mexico, the succession is given as Lewis shale, Mesaverde formation and Mancos shale. The term, Mesaverde, is indefinite; it is the sandstone member of the Pierre and is more or less coal-bearing. In some extensive areas it

[55] E. Stebinger, Bull. 621-*K*, 1916, p. 125; Prof. Paper 90-*G*, p. 62.

embraces practically the whole of the Pierre, while in others it but the middle portion. Mancos is another lithological term, designating the mass of shale underlying the Mesaverde, so that in many districts it includes the Lower Pierre as well as the Niobrara and Benton. The significance of the several terms will appear in description of the districts.

The Pierre in the Parks of Colorado and east from the meridian of the Front Ranges of Colorado consists mostly of shales, becoming sandy toward the top, with irregular lenses of limestone and, in the upper portion, huge calcareous and ferruginous concretions. Sandstone is wholly unimportant except in the Boulder district of the Denver Basin, where Fenneman saw,[56] at one third way from the base, the Hygiene sandstone, which is several hundred feet thick west from Berthoud, but only 250 feet at the north end of the district. The thickness of Pierre in this region is not fully determined; Eldridge gives 7,700 to 7,900 feet in the Denver Basin, but Fenneman gives only 5,000 in the Boulder district of that basin. Near Canyon City on the Arkansas River, oil-borings found 4,500 feet, while farther south on the eastern border of the Raton-Trinidad coal field, the thickness appears to be considerably less.

But the change is startling between the southern termination of the Raton field and Cerillos, a distance of about 100 miles in west of south direction. At Cerillos, one is on the same meridian with the Park area of Colorado, where the Pierre is almost wholly shale, whereas here it is largely sandstone. Some small isolated coal fields remain farther south. The Engle, unimportant from the economic standpoint, has coal-bearing rocks, which as Lee[57] has shown, rest on deposits of Benton age. Wegemann found similar conditions in the Sierra Blanca field about 80 miles west-northwest from the last. Both authors are inclined to refer the coals and associated rocks to the Mesaverde, because the general conditions resemble those observed farther north in the Cerillos field. In the absence of conclusive information, the writer is inclined to suggest that the coals may be of Benton age. The Sierra Blanca area is not far from 120 miles south from the Cerillos field and by so much

[56] N. M. Fenneman, Bull. 265, 1905, pp. 31, 32.

[57] W. T. Lee, Bull. 285, 1905, p. 240; C. H. Wegemann, Bull. 541-*J*, p. 10.

nearer the source of sediment. One should expect to find in that direction the same conditions as appear on the western border, where important coals occur in the Benton.

The Cerillos coal field, a few miles south from Santa Fe, New Mexico, has been examined by several geologists whose conclusions are not in agreement.[58] Stevenson thought that the coal-bearing group belongs to the Laramie; Johnson referred it to the Fox Hills; but Lee recognized the true relations and determined that it is Mesaverde, the Middle Pierre in this field. The coal group is about 1,200 feet thick and rests on Mancos shale, of which the top 150 feet carries Pierre fossils. The basal rock of the coal group is a sandstone, 300 feet thick and without coal. It has an assemblage of fossils which suggests Fox Hills conditions. The coal seams are numerous but variable. The sections of one bed at four openings, as given by Stevenson, are

Coal	1 ft. 2 in.	Thin	Streaks	Absent
Clay	1 ft. 3 in.	6 ft. 0 in.	12 ft. 0 in.	8–10 ft.
Coal	2 ft. 3 in.	2 ft. 5 in.	4 ft. 7 in.	3 ft. 10 in.
Coaly shale	3 ft. 5 in.	Absent	Absent	1 ft.

In one mine the coal has been replaced with sandstone in a space 75 feet wide and several hundred feet long, a case of contemporaneous erosion. Gardner[59] saw an apparently similar replacement in the Omera field, east from Cerillos. At 500 feet from the outcrop in a mine, the roof descended and cut out the coal. In 1879, Stevenson noted a ripple-marked sandstone and an underclay with roots.

The only information available for present purposes, respecting coal fields between Cerillos and the great San Juan Basin at the west, is contained in Lee's publications.[60] The Hagan field directly west from the Cerillos differs notably from the latter. The most striking difference is due to increase of Mesaverde at expense of the

[58] J. J. Stevenson, U. S. Geóg. Expl. W. of 100th Mer., Vol. III., Suppl., pp. 147 ff.; *N. Y. Acad. Sci.*, Vol. XV., 1896, pp. 105 ff.; D. W. Johnson, *Sch. Mines Quart.*, Vols. XXIV., XXV., 1903; W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 642, 658; Bull. 531-*J*, 1913; Prof. Paper 95-*C*, 1915, p. 41.

[59] J. H. Gardner, Bull. 381, 1910, p. 448.

[60] W. T. Lee, Bull. 389, 1909, pp. 5–40; *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 622–642.

underlying Mancos. The lower portion of Mesaverde in Cerillos is the great sandstone, 300 feet thick; but in Hagan it is about 900 feet, mostly sandstone, without coal and with Pierre fossils at several horizons. The coal group immediately overlying it is 180 feet thick with 5 coal seams, of which one has local importance. This averages about 3 feet in a small area and underlies a massive coarse sandstone, cross-bedded and containing petrified wood. Thin streaks of coal were seen in higher parts of the column. The whole thickness is about 1,850 feet and the upper half has no marine fossils. The Tijeras coal field, at 25 miles southwest, gives clearer evidence of land conditions. The lower portion of the Mesaverde is only 700 feet thick, but it contains 3 coal beds, 2 inches to 3 feet thick, proof that the broad sand flats were free from sea-invasion long enough to permit accumulation of peat in the hollows of their irregular surface. The lithology changes above the uppermost marine sandstone. Exposures are such as to make measurements indefinite, but the presence of what the writer takes to be the Cerillos coal group is distinct, for two coal seams, 3 feet and 1 foot 6 inches, were seen. This upper portion contains no marine forms. The basal deposit is a massive sandstone, 115 feet thick.

The Rio Puerco field, beyond the Rio Grande, is about 25 miles west from Hagan and Tijeras. Lee gives 1,700 feet as the thickness of Mesaverde, but thinks that the upper part has been removed by erosion. The Mancos (Colorado) shales are but 1,113 feet, whereas they are 2,350 feet at Cerillos. The Mesaverde has many horizons of marine fossils even to the top; but, at about 300 feet from the top as here exposed, it has a coal group, 185 feet, with 16 coal seams, all very thin; and another, about 100 feet thick, with one of the beds 6 feet thick, at 450 lower. Some of the sandstones contain fossil leaves in abundance. At the base is a massive marine sandstone, the Punta de la Mesa sandstone of Herrick and Johnson,[61] which is 77 feet thick. The former existence of another coal-bearing group is shown at the top of the column, where Lee found at some localities a shale with thin coal. At the same time it seems probable that the upper coal group represents that at Cerillos. Lee's suggestion that the 300 feet of marine sandstone and sandy shale at

[61] C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II., p. 6.

the top of the section may represent the Lewis shale is very far from improbable: there appears to be good reason for believing that the Mesaverde of Rio Puerco includes the whole of the Pierre, whereas at Cerillos, Mesaverde is Middle Pierre.

Pierre deposits are exposed on the borders of the great San Juan Basin. Information is lacking for the southern prong of this basin but is fairly abundant for the main part, northward from Lat. 35° 30′, though comparatively few details have been published. Gilbert,[62] during the reconnaissance in 1873, measured a long section of Cretaceous at Stinking Spring, 12 miles west from Fort Wingate in New Mexico. This shows about 700 feet of yellow shales, yellow sandstones with coal beds, resting on 1,050 feet of sandstones and mostly sandy shales. Of the 7 coal seams, 3 reach workable thickness; one of them is triple, the benches being 4, 5 and 2 feet, separated by 5 feet and one foot of shale. There is no coal in the basal 200 feet. The Cretaceous in this region is one lithologically; "characterized by sands, by coal, by rapid alternations, by ripplemarks and by oysters, it is evidently an off-shore deposit." But fossils offer basis for subdivision; they are abundant in the lower 850 feet, which may be taken here as representing the shore facies of Colorado or lower portion of the Mancos, as that appears in the type locality.

Thirty years later, Schrader[63] made a reconnaissance of the eastern side of the basin, from Gallup, near Fort Wingate, to the northern border in Colorado. The section is longer than at Stinking Spring and during the 30 years interval the coal bed had become important. He found shales and sandstones, 2,000 to 3,000 feet thick, with the Upper Coal Group in the lower part; shales and sandstones, 500 to 800 feet, with the Middle Coal Group near the top; and 500 to 1,000 feet of Colorado shale, with the Lower Coal Group near the top. The Upper Coal Group is about 100 feet thick and contains 6 workable coal seams, 5 of which have fireclay floors. The Middle Coal Group appears to be the same with that of Gilbert's section. The coal seams throughout appear to be irregular.

[62] G. K. Gilbert, U. S. Geog. Explor. W. of 100th Mer., Vol. III., 1875, pp. 544, 549, 550.

[63] F. C. Schrader, Bull. 285, 1906, pp. 242, 254, 255.

Gardner[64] afterwards examined this line more in detail. Here he regarded the upper and middle groups of Schrader as Mesaverde (here evidently in part Lower Pierre), to which he assigns a thickness of about 1,000 feet east from Gallup. The coal seams are numerous but variable; "within a few miles, thin beds undoubtedly thicken to valuable properties and thicker beds thin to mere traces."

Farther north between San Mateo and Cuba, the Mesaverde, 1,200 feet thick, is coal-bearing throughout. Near the top is the first appearance of the Lewis shale, which contains much sandstone and sandy shale. There, one is little more than 40 miles northwest from the Rio Puerco locality, where Lee found marine fossils at top of the Mesaverde and thought that the deposits might be the equivalent of Lewis shale. No trace of that shale is reported from any locality farther south in the San Juan Basin. Along this portion of the outcrop, the Mesaverde coal seams are in two groups, separated by 300 feet of barren measures; the seams are all lenticular and in several instances have bony coal at top or bottom or both. Gardner's observations north and west from Cuba are important. At a little north from Gallina, 14 miles north from Cuba, the Lewis is 2,000 feet while westward it becomes only 250 near Raton Spring. Gardner thinks this westward change due to replacement with sandstone, which has been regarded as Mesaverde. The condition southeast from Cuba confirms the suggestion, for there the Mesaverde is but 719 feet, with no coal in the basal 300 feet and only coaly shale or thin coals at widely separated horizons in the upper part. The thinning is more notable beyond Gallina, where the Mesaverde is but 214 feet and contains 14 coal seams, of which only one is of workable thickness. The coal is subbituminous, occasionally resinous and the seams are variable to the last degree. The Mesaverde is limited, top and bottom, by massive sandstones which persist although the section is decreased. Lee[65] states that Gardner's collections from Lewis shale and from Mesaverde south and southeast from Cuba, are marine. He saw great numbers of petrified stumps and logs in the lower part of the Mesaverde near Cabezon, where the upper part of the Mancos has Pierre fossils.

[64] J. H. Gardner, Bull. 341, 1909, pp. 339, 343, 345, 366, 372, 377; Bull. 381, 1910, pp. 463, 470.

[65] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 619–621.

It would appear from the observations by Lee and Gardner that, in this portion of the basin, the Mesaverde is again Middle Pierre. The sea area extended as a gulf southward as far as Cabezon's latitude and the sandy member of the Pierre must have disappeared at only a little way east from Gallina.

Shaler[66] examined the western outcrop in the San Juan Basin. He reports that Lewis shale, only 250 feet thick where first recognized at the south, becomes 2,000 feet farther north but diminishes to 1,600 feet at the northern outcrop. The Mesaverde, massive sandstone and thin interbedded shales and sandstones with coal seams at the south, shows the triple succession at the north, where the thickness is from 750 to 1,450 feet. He observed "horsebacks" and "rolls" in a Mesaverde seam near Gallup. Along the northern outcrop in Colorado, Cross and Spencer[67] found the highest member of the Pierre, named by them the Lewis shale, well defined. The Mesaverde, named by W. H. Holmes, is triple, the two great escarpment sandstones with between them a coal group of sandstones, marls and coal seams. The whole thickness in the La Plata quadrangle is barely 1,000 feet, that of the coal group being 600. The coal seams are variable and the authors look upon them as a series of lenses. The Mancos shale named by Cross, has Pierre fossils in the upper "several hundred feet," so that here also, one has the condition observed on the opposite side of the area, at Cerillos, where Mesaverde is the Middle Pierre. In the southern part of the San Juan Basin, it would appear that Mesaverde and Pierre are practically synonymous terms. Gardner's[68] observations are of interest in this connection. He traced the Mesaverde around the northern border from Durango, Colorado, to Monero, New Mexico. It is about 1,000 feet thick near Durango but decreases eastwardly, so that it is only 400 feet at the Piedra River, 60 miles from Durango. This is in accord with Schrader's observations and with those of Gardner in the Gallina area. One seems to be justified in suggesting that the Mesaverde disappears at a short distance east from the San Juan basin, giving place to the shales, which are present in

[66] M. K. Shaler, Bull. 316, Part 2, 1907, pp. 378, 414.

[67] W. Cross, "Telluride Folio, No. 57," 1899; W. Cross and A. C. Spencer, "La Plata Folio, No. 60," 1899.

[68] J. H. Gardner, Bull. 341, p. 353.

Colorado on both sides of the Front Ranges. Near Durango, three workable coal seams are present within a vertical distance of 110 feet, midway in the Mesaverde; these become insignificant toward the east and no workable seam was seen along the outcrop for more than 60 miles. But at Monero in New Mexico, three seams of workable thickness are present in a vertical distance of 100 feet above the basal sandstone.

The Uinta Basin extends from the westerly foot of the Wasatch Mountains in Utah into northwestern Colorado and has an area of not far from 10,000 square miles, being a little larger than the San Juan Basin. The Utah prong, known as Castle Valley, was examined by Taff and by Lupton, while Gilbert has given the section in the Henry Mountains about 50 miles southeast.[69] The highest Cretaceous beds in the Henry Mountains are the Masuk sandstone and Masuk shale of Gilbert, the former containing coal seams; it is thought by Lupton to be most probably Mesaverde. Lupton made no detailed study of the Mesaverde in Castle Valley, but estimated the thickness as not far from 1,200 feet and notes that it contains several important coal beds in a section of 500 feet, beginning at 200 to 300 feet from the base. Taff notes the triple structure of the Mesaverde, the two sandstones separated by the coal group. The coals are numerous but are important only in the lower 250 feet of the group. The coal is massive, bright, clean, bituminous and contains much resin. Partings are usually insignificant, but Taff saw one in a thick coal seam, which increased from nothing to 16 feet within 2,000 feet. The roof and floor of the coal seams are often sandstone.

Richardson examined the southern side of the basin between Sunnyside, Utah, and Grand River, Colorado, known as the Book Cliffs coal field.[70] The thickness of the Mesaverde is given as 1,200 to 2,200 feet, the variation being due to erosion. The underlying Mancos shale contains Pierre fossils in the upper 250 feet and is nonfossiliferous for a great thickness below; so that the Mesaverde is not lower than Middle Pierre. The sandstones of the formation

[69] G. K. Gilbert, "Geology of the Henry Mountains," U. S. Geog. and Geol. Survey of the Rocky Mountain Region, 1877, pp. 4–10; J. A. Taff, Bull. 285, 1906, pp. 292–294, 298; C. T. Lupton, Bull. 628, 1916, p. 34.

[70] G. B. Richardson, Bull. 371, 1909, pp. 7–39.

are lenses and are the marked features of the Book Cliffs; the lower members contain *Halymenites major* and brackish-water forms are present at many horizons. The coal seams of economic importance are confined to the lower 700 feet but Richardson's section makes clear that the importance in each case is confined to a small area and that the seams must be lenses. Near Thompson, Utah, at the southern point of the field, there are 5 seams, beginning at 490 feet from the base; near Price canyon farther north, are 7 beds, beginning at 340 feet, while near the Colorado line 6 seams were seen in the basal 275 feet, the lowest being only 95 feet from the bottom. On the Grand River the section shows 10 seams in the lower 519 feet. No coal seam has been traced for more than a few miles; one, 21 feet 6 inches thick, where mined, proved to be a mere lens, which disapeared quickly toward the west. Seams important at the east disappear toward the west. There are coal horizons, not continuous beds.

The Grand Mesa coal field and smaller fields farther east have been discussed by Lee,[71] who has made the relations clear for the region east from Grand River. The Upper Mancos is rich in Pierre fossils and the Mesaverde is 600 to 2,500 feet thick, the variation being due to erosion preceding deposition of newer formations. The upper part or undifferentiated Mesaverde, about 2,000 feet thick, is of fresh-water origin, mostly sandstone and contains little coal. It rests on the Paonia shale, closely allied to it lithologically, and about 400 feet thick. This has plant remains, fresh-water mollusks and important coal beds. Underlying this and separated from it in a considerable area by an unconformity, are the Bowie shales, 0 to 425 feet thick, with important coal seams and brackish-water as well as marine invertebrates. The basal deposit is the Rollins sandstone, usually about 100 feet thick, white, massive, with *Halymenites major* and marine invertebrates—evidently the basal white sandstone observed by Richardson in the Book Cliffs field.

Lee recognized a distinct unconformity below the Paonia; ordinarily, that formation rests on the Bowie, but for a considerable space in one portion of the region it overlies the Rollins. This leads

[71] W. T. Lee, Bull. 510, 1912, pp. 19, 37, 45, 81, 82, 86, 92, 95, 98, 106–109, 182, 188.

him to suspect that the unconformity may indicate a time interval and that possibly the Paonia and overlying rocks may not be older than Laramie. The unconformity is distinct, for the Bowie decreases from 425 feet on Grand River to nothing in the Rollins district; and it seems to be suggested on Grand River by the irregular contact between Paonia and Bowie at Palisades. It may be injudicious, it may savor of temerity for one who has not visited the localities to controvert the opinion of one who has examined the area in detail, especially when the latter is a model of accuracy in observation and caution in conclusion, but the writer feels compelled to believe another explanation not improbable. The vast area of Cretaceous deposition was subsiding until certainly toward the close of the Cretaceous as was the Appalachian Basin during Coal Measures time: but there were local crumplings as there were in the Appalachian. In the latter, these have left their records in deep stream valleys, filled with later deposits. Similar conditions have been observed in the British coal fields. It would be strange if evidences of local elevations or depressions were wanting in the vast subsiding Cretaceous region. The irregular contact on Grand River seems to indicate change in direction of drainage on the broad plain.

A serious argument in favor of assigning Laramie age to the Paonia and overlying deposits is the presence of a flora, which is described as containing Montana Laramie and even Post-Laramie forms, the Montana forms being few. The origin of a flora is a perplexing problem, but there seems to be no reason to suppose that it sprang into existence full-formed and without local forerunners, probably at many places. But, be that as it may, the Bowie and the Paonia appear to be continuous in the eastern part of the region described by Lee and no plane of separation has been determined. Farther north, just beyond the existing limits of the Uinta Basin, the Lewis shale has been recognized. It seems not unreasonable to suggest that in the southern part of this basin as in the southern part of the San Juan Basin, fresh-water sandstones may hold the place of the Lewis. The doubts must be dispelled by stratigraphy. The "Fox Hills" and "Laramie" of the earlier students have been placed in the Pierre, in spite of the remarkable resemblance to the later

formations. If the deposits under consideration underlie the Lewis, they belong to the Pierre.

The undifferentiated Mesaverde on the western border of Lee's area consists chiefly of massive cliff-making sandstones, about 1,500 feet thick, containing deciduous and conifer leaves as well as *Sphærium, Physa* and *Goniobasis*. Within 22 miles eastward, of about 1,000 feet exposed, 700 feet are shales; it may be described as shale with thick partings of sandstone, while near Bowie in the Somerset district the shale feature becomes much more marked; but in Crested Butte district, the southeastern part of the basin, it consists of sandstones separated by layers of shale. The coal seams throughout are thin.

The Paonia shales, at several horizons, are rich in fossil leaves and fresh-water mollusks. The lowest coal seam, Cameo of Richardson, is at 4 to 10 feet above the great sandstone at top of the Bowie; in the western part of the area studied by Lee, this coal horizon seems to persist throughout the whole region. This coal is double at Rollins, 3 and 11 feet with parting of 2 feet. Thin seams are at 80,123 and 219 feet higher at Cameo on Grand River; but in the Rollins district 3 workable seams were seen in 108 feet above the base. Similar irregularity was observed in the easterly districts, so that one must look upon the coal seams as lenses. The quality is as variable as the quantity of coal. In one mine on the lowest seam, irregular masses of white sandstone descend from the roof and occasionally extend across the bed. Cross-bedded sandstone was seen midway in the section at several localities.

The Bowie shale, 420 feet thick on Grand River, has a sandstone, 100 feet, on top, cross-bedded, with worm tubes and *Halymenites*. Only one coal seam is there, about 430 feet below the Cameo bed; this is unimportant and thins away toward the south. There is no Bowie in the Rollins district, but it reappears farther east in the Somerset district, where, near Bowie, it is 405 feet and has the great top sandstone. The coal seams are numerous and at least 7 of them are "relatively thick," aggregating 38 to 43 feet in this district. The thickness of other seams has not been determined. The coals are exceedingly variable and they may be only extensive lenses; but some of them attain notable thickness. The Juanita bed is 12

feet in one mine near Bowie but 21 in another and 22 near Somerset; while at another locality, no trace of it could be found. At the Johnson prospect, on Minnesota creek, east from Paonia, 9 coal seams, 2 to 8 feet thick and with total thickness of 43 feet, were seen in the lower 300 feet of the Bowie. At the Simonton prospect, about 4 miles toward the south, the exposure shows this section, beginning at 37 feet above the Rollins sandstone: coal, 2 feet, 10 inches; shale, 10 inches; coal, 1 foot, 2 inches; shale, 5 inches; coal, 13 feet, 1 inch; shale, 6 feet; coal, 16 feet; bony coal, 2 feet; coal, 7 feet, 2 inches; in all 49 feet, 6 inches.

The presence of this great mass is perplexing. One cannot trace the section from the Johnson prospect and Lee concludes that the Simonton seam is due to the coalescence of 7 seams of the Johnson section, or that it is a merely local deposit. The Bowie becomes irregular in districts farther east, sometimes present, sometimes absent, and the coals are extremely variable in thickness and quality.

Lee's notes show that mineral charcoal is present in most of the coals. Toward the Elk Mountains, the region is greatly disturbed by plication and by eruptive rocks; the coal is from subbituminous to hard dry anthracite. The seams are thicker on anticlines than in synclines. In some localities, the stream channels, due to contemporaneous erosion, have been filled with white sandstone.

On the northwestern side of the Uinta Basin, there is a mass of deposits, 0 to 3,300 feet thick, which Lupton[72] places in the Mesaverde—the variation in thickness being due to erosion prior to deposition of the Wasatch beds. The lower half in this Blacktail Mountain coal field is marine, without coal and is mostly sandstone with sandy shale and some limestones. The upper half, apparently fresh-water, has coal with sandstones, thin-bedded and cross-bedded. as well as much sandy shale. This upper division has 21 coal seams in 1,500 feet, 7 inches to 15 feet thick. One seam has a maximum thickness of 21 feet with only a single parting, 2 inches. The coal is resinous at some places.

Gale[73] has given some notes respecting the northern outcrop. He reports the Lewis shale as about 1,000 feet thick and without

[72] C. T. Lupton, Bull. 471-*I*, 1912, pp. 27, 32, 33, 39, 41.

[73] H. S. Gale, Bull. 341, 1909, pp. 287, 289, 290, 299; Bull. 316, 1907, p. 273.

sandstone. The Mesaverde, 5,000 feet at the east, where erosion was less energetic, has three coal groups. The lowest is in the basal part of the formation and underlies a conspicuous white sandstone, which contains marine fossils. Gale's description suggests that this sandstone may be equivalent to the Rollins of Lee and that the lowest coal group may be in the Lower Pierre, included farther south in the Mancos shale. The coal seams are usually thin and where thick are worthless. The middle coal group, above the white sandstone, is unimportant west from the Utah line, but the seams become thicker toward the east, though they are irregular and at times are broken badly by partings of shale or bone. They become important in the eastern part of the basin; at Newcastle, there are 105 to 108 feet of coal in 7 seams, the thicknesses being 5, 8, 20, 5, 45–48, 18 and 4 feet respectively. One seam at Newcastle has a parting of soft coal at 4 to 6 feet from the floor and is troubled by "sandstone dikes." A seam at 40 miles south from Glenwood Springs has 7 to 10 feet of coking coal as the upper bench, but the lower bench is non-coking. The upper coal group is near the top of the Mesaverde; its coals are unimportant.

The Green River Basin, north from the Uinta Mountains, is mostly in Wyoming but the southeastern prong extends into Colorado and an outlier remains in Utah at the west.

The relations of the upper part of the long section in the Coalville coal field in Utah appear somewhat uncertain. The area was studied by Taff and later by Wegemann, the paleontological determinations being made by Stanton.[74] The boundaries of the several formations are still indefinite, but it is sufficiently clear that the region was near the source of sediment, for sandstone and sandy shale predominate in the upper 7,000 feet of the section. The upper 2,500 feet, prevailingly sandy, has yielded leaves and fresh-water shells. The succeeding 1,650 feet contains marine shells and rests on a white sandstone, 200 feet; below that is a coal seam. This, at 4,450 feet below the top of the Cretaceous, is irregular in occurrence as well as in its relations to the thick sandstones above and below it. It is double or triple at many localities, while at others

[74] T. W. Stanton, Bull. 106, 1893; J. A. Taff, Bull. 285, 1906, pp. 285–288; C. H. Wegemann, Bull. 581-*E*, 1915, pp. 163, 182.

it could not be found. At one locality, a seam belonging at or near to this Dry Hollow horizon underlies a bed of oyster shells, 20 feet thick. The quality of the Dry Hollow coal is good, but the bed is too variable, so that no mines of any importance were in operation at the time of Wegemann's examinations.

No coal of economic importance has been reported from the Pierre of Uinta County in Wyoming, but in southern Sweetwater County, where Gale[75] recognized Lewis, Mesaverde and Mancos, he saw in one exposure two seams, 8 and 10 feet thick, separated by only 25 feet. The coal is not persistent and, within a short distance, it becomes black shale with coaly streaks. The lower seam is separated by one foot of bone from a thick white sandstone. Farther north in the same county is the Rock Springs coal field, intersected by the Union Pacific Railroad. There Schultz[76] recognized the Lewis shale, without coal, and the Mesaverde, consisting very largely of sandstone with important coal seams. The "Laramie" of Schultz is not everywhere conformable to the underlying Pierre. The unconformity is especially marked on the south and west sides of the Rock Springs Dome, where the "Laramie" rests on the Rock Springs coal group, a hiatus of fully 2,500 feet; but the succession is complete and conformable throughout on the west side of the Dome. Elsewhere there appears to be no unconformity.

The important coal seams are in the Almond and Rock Springs groups, separated by 800 to 1,000 feet of mostly massive sandstone, more or less conglomerate in the upper third with pebbles of gray and black quartz. The Almond coal group, 700 to 900 feet thick, contains many seams of coal and of carbonaceous shale. The seams are variable, though less so than are those in the Rock Springs group, but the coal is comparatively poor and no works were in operation at the time of Schultz's examination.

The coals of the lower or Rock Springs group are black, with distinct bedding planes and do not slack on exposure. The coal-bearing portion is about 1,275 feet with 37 seams containing in all somewhat more than 110 feet of coal. Five seams have been opened

[75] H. S. Gale, Bull. 341, pp. 310–314.

[76] A. R. Schultz, Bull. 341, pp. 256–382; Bull. 381, pp. 214–281.

near Rock Springs, but most of the coal has been taken from numbers 1 and 7, at 481 and 743 feet from the top of the group.

Number 1 has many "rock-slips" or "horsebacks," long, slim wedges of white sandstone, protruding usually from the floor. They are smooth on one side, rough on the other and the coal is unchanged even at the contact. The roof and floor are brownish to white sandstone. The coal, at times, is 10 feet thick, but changes are abrupt. Partings thicken and the coal becomes worthless. In one mine the coal is 11 feet thick and clean, but in another, adjoining, the coal suddenly became worthless and, at a little distance beyond, it pinched out. Seam 3 shows similar complications. A band of shale appeared in one mine at 2 feet from the floor; within a short distance it thickened upward until the top bench became too thin for working; but within 200 feet the foreign matter almost disappeared and the upper bench was again more than 5 feet thick. Schultz's description shows that here is a channel originating during growth of the swamp and filled up before the growth ceased, so that the swamp covered it. Seam 7 is less inconstant than the others but it is far from free from troubles. The roof and floor are shale, the former black. One important mine was abandoned because the good coal was replaced with worthless stuff in an area of evidently great extent. The Rock Springs coal seams become unimportant southwardly and none has been discovered in the extreme southern portion of the field.

Tertiary deposits conceal the Cretaceous from the Rock Springs field to near Rawlins in Carbon County, where Smith[77] recognized the Lewis, Mesaverde and the shales of Lower Pierre. The Mesaverde, consisting of sandstones, shales and coal seams, is still distinct but is much thinner than in fields farther west. It consists of two massive sandstones separated by a mass of soft brown sandstones and white to gray shale. The Almond and Rock Springs coal groups have become insignificant. The coal seams in this area are on top and at base of the upper sandstone and just above the lower sandstone: four or more seams were seen in the upper zone, few were observed in the middle and 4 to 6 in the lower zone. The

[77] E. E. Smith, Bull. 341, pp. 220–242.

coal throughout is inferior and the seams, for the most part, are too thin to be mined.

Beyond Rawlins and still north from the Union Pacific Railroad, Veatch[78] studied the coal field of east-central Carbon County, where the Pierre consists of Lewis, Mesaverde and Lower Pierre, with a total thickness of almost 8,000 feet, not far from that given by Smith; but in both districts the thickness decreases greatly toward the north. According to Veatch, some important coal seams are present in the lower part of the Lewis, evidently those belonging to the highest zone of Smith. Seams in the middle zone of the Mesaverde occasionally become thick enough for mining, but they are irregular and not persistent. The southern part of Carbon County, where the subdivisions of the Pierre are as in the northern part of the county, was studied by Ball and Stebinger.[79] The thickness of Lewis and Mesaverde decreases eastwardly, becoming 1,600 and 2,000 feet. The Lewis has no coal. The Mesaverde still has the two limiting sandstones with the middle shale and sandstone member. The basal sandstone is white gray and brown, cross-bedded and, in the eastern part of the district, contains a limestone, 25 feet thick. The top sandstone is less distinctly cross-bedded and the layers are thinner. No workable coal seams were seen in the sandstone members, at the north, but the number and thickness of those in the upper sandstone increase toward the south. Some important seams are in the middle member near Rawlins, but they disappear toward the northeast. The coal is hard and bituminous. The sandstones of this member are irregular and the coal seams appear to be overlapping lenses.

The Yampa coal field, in Routt County of Colorado, is the extreme southeast part of the basin. One can recognize in the section by Fennemann and Gale,[80] Lewis, Mesaverde and the lower shales, Mesaverde being Middle Pierre; the relations are more allied to those of the western than to those of the northern part of the basin. There are three coal groups, which in some portions of the field are in a vertical space of 2,000 feet, the lowest being about

[78] A. C. Veatch, Bull. 316, 1907, pp. 244–366.

[79] M. W. Ball and E. Stebinger, Bull. 341, pp. 243–355; Bull. 381, pp. 186–213.

[80] N. M. Fenneman and H. S. Gale, Bull. 285, 1906, pp. 226–239.

1,200 feet from the base. Each coal group has 2 to 3 workable coal seams, but the number and thickness of the seams vary from place to place. At the time when this field was examined, the population was sparse and none but insignificant mines had been opened. In the eastern part, coal seams, 4 to 10 feet thick, were exposed in both the middle and the lower group; but the upper group is ill-exposed. Farther west, seams of greater thickness were seen, one near Lay being 20 feet, with a parting of 15 inches midway. There, the three coal groups are in a vertical space of not more than 800 feet. Many seams have shale roof and floor and one is clearly between sandstones. A faux-toit was seen in many openings and either bone or dirty coal is the usual parting. A faux-mur is recorded in but one instance.

The irregularity in thickness of the Mesaverde in the Yampa field may be due to the eastward disappearance of shore conditions. At 25 miles east from the boundary of the Yampa field, Beekly's[81] sections on the west side of North Park show no evidence of Mesaverde, while at 25 miles farther east in the same Park, the Pierre is represented by about 4,500 feet of shale, wholly like that beyond the Front Ranges in Colorado and New Mexico. It is sandy on top and passes into a marine sandstone, shown on east side of the Park—apparently the Fox Hills. Some thin sandstones were seen in the lower part of the formation but no trace of coal is reported by Beekly.

Northward in Wyoming and east from the Medicine Bow Mountains about 60 miles east of north from the exposures in North Park, the section by C. E. Siebenthal, cited by Darton,[82] shows about 5,500 feet of Montana rocks, divided at about 1,300 feet from the top by the Pine Ridge sandstone, 60 to 80 feet thick. The mass is practically shale throughout, there being in all only 127 feet of sandstone in the upper 1,332 feet and 35 feet in the underlying 4,150 feet. The formation contains marine fossils at many horizons, the highest being within 140 feet from the top. It is difficult to determine a positive plane of separation between Pierre and Fox Hills in this region so that authors frequently employ "Montana" or

[81] A. L. Beekly, Bull. 596, 1915, pp. 20, 43, 45.

[82] N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, 1908, 459, 460.

"Pierre-Fox Hills." to designate the whole mass. Just above the one persistent sandstone, Pine Ridge of Siebenthal, is a coal bed and others, unimportant, are in the succeeding 560 feet of black shale; but in the overlying beds no coal was found. It may be that the upper part of the section, including the Pine Ridge sandstone, is equivalent to Mesaverde, Lewis and Fox Hills, the coal being in the Mesaverde.

Farther west in Fremont County, north from Sweetwater, the lower shales are 2,250 to 3,000 feet, increasing eastwardly, while the upper division, of which erosion has spared 550 feet, has at base a sandstone, 200 to 250 feet thick. Overlying this is a bed of carbonaceous shale, which occasionally contains a seam of coal. Here the Mesaverde conditions are distinct for the overlying mass consists of "sandstones, with intercalated gray shales, sandy shales and coal beds." The lowest coal is 8 feet thick at 10 miles east from Lander.

The Pierre is without coal[83] in the Black Hills and is wholly shale. The Sussex field at 100 miles southwest from the Black Hills has, according to Wegemann, 4,650 feet of Montana rocks, of which he refers the upper 700 feet to the Fox Hills. The Pierre has a sandstone, 175 feet thick, at about 1,000 feet from the base and, at 2,300 feet, another sandstone, the Parkman of Darton's Bighorn section, 350 feet. This sandstone contains masses of petrified wood with shells of turtles and bones of *Trachodon*. In the shaly portions near the base, it has thin seams of low-grade bituminous coal, high in ash. Thin seams are associated in the southern part of the field with another sandstone, about 300 feet above the Parkman. The Pierre rocks are predominatingly shale. The fauna of the Parkman sandstone, according to T. W. Stanton, is similar to that of the Mesaverde in Colorado and of the Claggett in Montana.

The Bighorn Basin of north central Wyoming lies west from the Bighorn Mountains, occupying parts of several counties and extending into Montana. It was examined by Washburne and Woodruff and in part by Darton.[84] The indefinite relations of the upper

[83] N. H. Darton, Folios 127, 128, 1905.

[84] N. H. Darton, Prof. Paper 51, 1906, pp. 13, 58, 59; E. G. Woodruff, Bull. 341, pp. 204, 208–210, 215; Bull. 381, pp. 173–175, 178; C. W. Washburne, Bull. 341, pp. 168, 172–179, 187, 195.

part of the column near Bighorn Mountains are shown by the fact that Darton embraces the whole above his Parkman sandstone in a single formation, the Piney. Woodruff in the southeastern part of the basin found indefiniteness throughout, but the succession is suggestive of the section as recognized in Montana and northward, there being at base shales with Pierre fossils succeeded by two sandstone and shale members which he referred provisionally to the Eagle sandstone and Claggett shale of Montana, while he terms the higher beds merely Undifferentiated Montana. All become more shaly toward the east. Coal seams were seen in the upper division, but they are lenticular and unimportant: the quantity decreases toward the north. In the western portion, Woodruff recognized the Eagle sandstone of the Montana section, but none of the higher divisions could be identified. Coal seams in the Eagle are lenticular, but occasionally they are important. One near Gebo is 11 feet thick; in Grass Valley, a seam, 7 to 8 feet, is mined, but within a fourth of a mile toward the west it is too thin to be worked, while, at an equal distance toward the south, it becomes much thinner and so broken by partings as to be worthless. Similar variations in the Eagle coals were observed elsewhere within this portion of the field. Farther south in the Buffalo Basin no coal has been found in the Eagle. The Undifferentiated Montana has some coal seams but they are wholly unimportant.

In the northeastern part of the basin, extending into Montana, Washburne was able to recognize all members of the Pierre as they had been determined in Montana—Bearpaw shale, Judith River Formation, Claggett shale, Eagle River sandstone, the last resting on Colorado shale. The Bearpaw, evidently the Lewis of localities farther south, is marine, 150 feet thick and without coal; the Judith River variegated clays and sandstone, 300 to 400 feet, has abundance of leaves and bones but seems to be without coal; the Claggett, 400 to 500 feet, consists of massive gray to yellow sandstone with interbedded shales and has marine fossils in many portions; the Eagle, 150 to 225 feet, has two or three massive sandstones. The upper part of the Colorado shale, for 1,000 feet, is without fossils, but it differs lithologically from the shales below and it may be taken as, at least in part, representing the lower shales of the Pierre as in the

southern portion of the Bighorn Basin. Coal is present in the Claggett and the Eagle. The Claggett seams are very thin, nowhere exceeding 21 inches, and in all cases the coal is so dirty as to be worthless. The Eagle seams are of capricious distribution. There are workable beds in the southeastern corner of the basin, but they disappear northwardly before Bighorn County is reached and are replaced with yellow sandy shales. Black shales appear north from the city of Basin and these near Garland contain very thin seams of coal. Elsewhere in that neighborhood, these coal horizons are marked only by black shale with coaly streaks. An anticline near Silvertop, close to the Wyoming-Montana line, brings up the Eagle. There is but one workable seam in that formation on the Wyoming side, but there are two beyond the line in Montana. The Bridger coal field is west from the anticline and extends along the Chicago, Burlington and Quincy railroad to beyond Bridger in Montana. Some important coal deposits are in the Montana portion, but none in Wyoming, and all trace of coal disappears at a short distance west from the railroad. The Eagle coals are all well-jointed and show no woody structure. They illustrate well the irregularity of coal deposits in an extended area.

The eastern part of Montana is a rolling plain, the mountains of Wyoming, Colorado and New Mexico having become insignificant, as the disturbed area is confined to the western border; but mountain-making was energetic there, west from the 109th meridian, and the whole section of Cretaceous is shown at many localities. In this disturbed area, one is west from the Bighorn Basin, as well as the western boundary of Colorado and New Mexico, so that conditions should bear resemblance to those observed in Arizona, Utah and western Wyoming.

The most southerly coal field is that near Electric, in Park County, about 100 miles west from Bridger. There as well as in some petty areas at the north, Calvert[85] was unable to recognize the subdivisions of the Pierre and grouped the section, about 1,000 feet, as Montana. The upper portion, about 330 feet, consists of sandstone and shales with some carbonaceous shale but no coal; the middle portion, about 230 feet, is largely sandstone and sandy shale

[85] W. R. Calvert, Bull. 471-*E*, 1912, pp. 28–66.

with several beds of dark shale and some seams of coal; the lower portion, about 370 feet, and without coal, is sandstone except 78 feet of sandy shale at the top. Four coal seams were seen in one section, three of them thick enough to be mined; but the coal is very dirty; that from the best contains 20 to 24 per cent. of ash and the washed coal, utilized in making coke, retains 21.71 per cent. This Montana of Calvert rests on a mass of shale and sandstone containing Colorado fossils throughout; which makes probable that basal member of the section may be equivalent to the shales of the Lower Pierre and that the coal-bearing member may be at the Eagle or Mesaverde horizon, there being Mesaverde fossils throughout. The "Montana" beds underlie conformably the Livingston formation, a mass of andesitic material. Calvert found similar conditions in the Livingston coal field farther north in the same county, except that his Montana beds are thinner. There are not less than 3 seams of coal, 2 to 20 feet thick; but they vary rather abruptly in thickness and the coal is of uncertain quality. Two samples from one mine gave 8.77 and 17.5 per cent. of ash; analyses of samples from other mines yielded 8.44, 10.92, 10.99, 14.9, 27.53 and 31.51 per cent. in air-dried coal. Cross-bedded sandstones were noted by Calvert in both fields.

Newberry[86] noticed that coal near Bozeman, in the Livingston field, contains a large quantity of yellow, translucent, almost amber-like resin. Weed[87] examined the same fields at an earlier date and called especial attention to the uneven floor of the coal seams. This as well as the occasional disappearance of the coal led him to believe that the coal seams had been formed in depressions of the surface. He found *Unio* in beds associated with the coal seams of the Electric coal field.

In Meagher County, north from Park, Stone recognized the four formations. The Bearpaw shale, marine throughout, has no coal; the Judith River, brackish and fresh water, has some lenses of coal, usually very thin and of short lateral extent; when of workable thickness, their coal is apt to be dirty. The Claggett, marine and brackish, appears to be without coal. The Eagle has coal, but

[86] J. S. Newberry, *Ann. N. Y. Acad. Sci.*, Vol. 3, 1884, p. 245.

[87] W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 2, 1891, pp. 349–364.

it is uncertain both as to quantity and quality; when a seam becomes thick it has much foreign matter and is in great part worthless. Stone could not determine whether or not the Eagle coals are lenses; but the quality is inferior with from 17 to 37 per cent. of ash. Here, as in districts farther south, the rocks are mostly sandstone and sandy shale.

The Lewistown coal field in Fergus County is about 60 miles north-northeast from the Meagher area and its western limit is near the 110th meridian. Calvert[88] found no rocks newer than the Claggett, which like the underlying Eagle, consists of sandstone and sandy shale; cross-bedded sandstones are characteristic. The only coal seam is in the Eagle, at 10 feet from the base. It is merely a coaly layer. Bowen[89] examined the Cleveland field, about 80 miles east of north, and the Big Sandy field at an equal distance west of north from Lewistown. In both fields the Judith River and the Eagle are characterized by irregularity of the deposits and the sandstones are often cross-bedded, occasionally ripple-marked. The Eagle becomes shaly in the eastern field. Thin seams of impure coal were seen in the Judith River within both fields; the Eagle has similar streaks in the southern part of Big Sandy but no coal was seen in the northern part of that field nor in the Cleveland field. The Eagle coal is usually bony.

The Milk River coal field is north from the Cleveland and extends to the Saskatchewan line. Pepperberg[90] states that the Judith River coals, all near top of the formation, are lenses, which become thinner and poorer toward the east. The variation in thickness is abrupt; a lens, 9 feet thick, decreased to a fraction of an inch within a short distance along the outcrop. The quantity of bone is a serious drawback in many mines, so that the product is inferior, because of high ash. The coal is subbituminous and contains mineral charcoal as well as resins. All deposits in the Judith River are lenticular and the sandstones are locally cross-bedded. Some streaks of coal were seen in the upper part of the Eagle, but they are insignificant. The sandstones of both formations have become much less prominent.

88 W. R. Calvert, Bull. 341, p. 110; Bull. 390, pp. 32, 34.
89 C. F. Bowen, Bull. 541-*H*, 1914, pp. 45–47, 60–65, 77–80.
90 L. J. Pepperberg, Bull. 381, pp. 85, 86, 94.

Teton County is very near the western boundary of Cretaceous deposition in Montana. It reaches the border of Alberta and the coal-bearing area is between meridians 112° 30′ and 113°. Stebinger's[91] report on this area and his general discussion of the Montana Cretaceous have done much to solve serious problems in correlation. The succession in the Teton coal field is St. Mary River formation, correlated with the Laramie; Horsethief sandstone, 225 to 275 feet, which Stebinger has shown to be same as the Lennep sandstone and the Fox Hills; Bearpaw shale, with characteristic features of the formation, 490 feet; Two-Medicine formation, 1,950 feet, gray to greenish gray and whitish clay shales, with some sandstones, which are important in the basal 250 feet; Judith River leaves, mollusks and bones of reptiles are present; it is apparently continental in origin, there being evidence of only one marine invasion, and that is at about 200 feet from the base. The formation includes Judith River, Claggett and the upper or coal-bearing portion of the Eagle. The marine deposit near the base contains the Claggett-Fox Hills fauna, indicating deposition in a retreating sea. Within the disturbed region on the western side of the county, one finds it difficult to distinguish this formation from the St. Mary; the conditions during deposition must have been very similar in both. Virgelle sandstone, 220 feet, the basal sandstone of the Eagle, is gray to buff, coarse, cross-bedded sandstone, becoming slabby to shaly in the lower half.

Two-Medicine and Virgelle, traced northward into Alberta, prove to be the Belly River formation, described by G. M. Dawson. The Two-Medicine is characterized by extreme irregularity of the beds; sections only a few hundred feet apart are wholly dissimilar. Fossil wood is distributed throughout the formation, knots and entire sections of compressed trunks of trees are of common occurrence. The continental deposits, except the Fox Hills, become thinner toward the east, so that in the Black Hills of northeastern Wyoming the Pierre is represented only by marine shales.

No coal aside from petty lenses was seen in the Virgelle; the Two-Medicine has three coal zones, one at the base, another at 250

[91] E. Stebinger, Bull. 621-*K*, 1916, pp. 126, 127, 131, 140, 144; Prof. Paper 90-*G*, 1914, pp. 61–68.

feet higher and a third at the top, but coaly material is present in other portions as carbonaceous shale. The highest coal is found in the northern part of the county, but it disappears south from Valier, about 50 miles from the International Boundary and no trace of it has been found farther south in a distance of not less than 50 miles. It is thin in Teton County but increases toward the north beyond the boundary and is 6 feet thick at Lethbridge, where the coal is good. The seams of the middle zone are thin and yield only impure coal, while the lower zone has two seams which are persistent in the Valier district on the easterly side of the county. The upper one is 2 feet 6 inches, with 2 feet of coal, while the lower one, with extreme thickness of 5 feet 8 inches, contains only 8 inches of clean coal. These seams vary much in thickness, but the upper one is mined. Samples of clean coal gave 14.07, 13.9, 14.5 and 28.6 per cent. of ash.

Dowling,[92] in his synopsis of conditions in the western states of Canada, says that the depressions, in which Mesozoic rocks were deposited, appeared in the Rocky Mountain area, where Triassic and Jurassic beds are found. The Jurassic sea invaded a narrow depression, now elevated as the Rocky Mountains and the Foothills. Land conditions prevailed during part of the Lower Cretaceous, but occasional submergences extended to a short distance toward the east, whereas in the United States they extended as far east as the Black Hills of Wyoming. More general submergence eastwardly came in the Upper Cretaceous, while on the western side there is evidence of shallowing during the earlier periods. Marked proof of shallowing on that side is evident during the Montana, for land conditions are shown by the coal seams and by the type of sediments, but marine conditions prevailed at the east. Submergence followed and the sands at the west were covered with marine shale. The closing part of Cretaceous time was characterized by emergence, with brief periods of submergence, as shown by land and shallow water conditions, giving an abundant flora and a brackish-water fauna: this closing stage is the Edmonton-St. Mary formation. The vast accumulations unsettled the equilibrium of the area whence they had been derived and, toward the close of the

[92] D. B. Dowling, Geol. Survey of Canada, Mem. 53, 1914, pp. 32, 33.

Eocene, crustal movements followed, which formed the Rocky Mountains. But the energy was expended in a narrow area so that at the east, even in the Foothills, one finds nothing exposed below the Middle Cretaceous.

The conditions noted by Dowling are very distinct in southern Alberta. McEvoy, in the mountain portion of the Crowsnest coal field, found the Upper Cretaceous merely a mass of sandstone and conglomerate, 7,000 to 8,000 feet thick and without coal. In another part of the Rocky Mountain area, near the International Boundary, McConnell saw no coal in the upper part of the section, which contains great beds of conglomerate, some of them 150 feet thick. It seems to be impossible to differentiate the formations in this area; but McLearn, at a short distance eastward in the Foothills, recognized the Bearpaw and the Belly River, the latter being the equivalent of Judith River, Claggett and Eagle.[93] The sea-invasion during Claggett did not reach much of southern Alberta and did not extend so far westward as did that during the Bearpaw. No coal was seen in the basal sandstone of the Belly River formation, but 4 thin seams were seen in the overlying 50 feet of clay and shale. The higher deposits are sandstones and shales, alternations of "sand bottoms and clay bottoms" with *Unio* and gastropods in the sands and gastropods in the clays. The faunules are fresh-water. Mackenzie[94] saw no coal in the Allison (Belly River) formation on Oldman River, where it is 2,000 feet thick and consists chiefly of sandstones, massive to shaly and often cross-bedded.

Dawson[95] examined an extensive area within southeastern Alberta, mainly along the Bow and Belly Rivers, but reaching into the Milk River region near the International Boundary. He offered tentative names for the formations. The Pierre shales, 750 feet thick, contain intercalated beds of sandstone, which increase toward the mountains. A coal zone was seen at the top on Bow River and another at the base on Belly River; the latter was seen also at several

[93] J. McEvoy, Ann. Reps. Geol. Survey Canada, Vol. XIII., 1900, Part *A*, pp. 84–88; R. G. McConnell, the same, 1886, Part *D*, pp. 16, 17; F. H. McLearn, Summary Report, 1914, pp. 62, 63.

[94] J. D. Mackenzie, Summary Report for 1912, pp. 235–246.

[95] G. M. Dawson, Geol. Survey of Canada, Reps. Prog. for 1882–83–84, Part *C*, pp. 36, 52, 62, 69, 71.

places on St. Mary River. At the mouth of the latter river, in a section by R. G. McConnell the lower zone has 3 coal seams in a vertical distance of 132 feet, the thickest being from 3 feet to 3 feet 6 inches. This zone is persistent and its coal is mined on Belly River. The Belly River formation has few thick coal seams; its sandstones are gray to yellow, hard and the surfaces often show ripple marks and worm trails. In one case, the ripples indicate movement toward S. 36° W. The "Lower Dark Shales" of Dawson were seen on Rocky Ridge in the Milk River region. Dowling[96] has shown that the Pierre shale is the Bearpaw, the Belly River of southeastern Alberta is the Judith River and the lower dark shales of Rocky Ridge are the Claggett. Evidently he places the coal of Dawson's Pierre in the upper or fresh-water part of the Belly River. The area within Alberta, in which the Belly River with its important coal seams is exposed, is not less than 24,000 square miles; its presence has been proved by borings in a great area, where it is deeply buried under later formations. In a report on the Sheep River Oil and Gas field, Dowling has emphasized the increasing thickness of Bearpaw toward the east; in the Foothills, it is 650 feet, on Red Deer River, east from Calgary, 750, on the Cypress Hills, 900 and on Sheep River, about 1,200 feet.

The coal seams of the Pierre formations become unimportant north from the latitude of Edmonton. They are few and thin, sometimes wholly wanting, as appears from observations by G. M. Dawson,[97] Dowling, Tyrrell and McConnell. Dawson found no seam thicker than 6 inches on Pine River. The associated rocks are sandstone and sandy shale, the former cross-bedded and ripple-marked. On Smoky River he saw a soft massive sandstone, with abundant fragments of plants, which in one place are "distinctly representing the base and roots of a tree, and evidencing a terrestrial surface. Overlying this is a thin carbonaceous film which, at a short distance up the river, becomes a seam of lignitic coal, two and a half inches in thickness." The Dunvegan sandstone of Peace River, regarded as the Belly River formation, has no coal.[98] It disappears toward the east and is not present on Athabasca River.

[96] D. B. Dowling, Mem. 53, 1914, pp. 28–31, 51, 53.

[97] G. M. Dawson, Rep. for 1879–80, Part *B*, pp. 117, 118.

[98] R. G. McConnell, Reps., Vol. VI-*D*, 1893, p. 53.

The Colorado Group.

The Niobrara and Benton are sufficiently distinct in the region of the Front Ranges and eastward as far north as Wyoming. The Niobrara consists of black shales and limestones weathering to chalky whiteness; while Benton is mostly shale, but with bands of sandstone and more or less persistent limestones. Farther west, however, the deposits answering to the Niobrara-Benton time interval lose the limestones and the mass becomes practically continuous as shale, though varying much at different horizons. The term Colorado Shales finds application in those areas, where Niobrara cannot be recognized and where Benton conditions, as shown at some places by the continuing fauna, remained comparatively unchanged. The term Mancos was introduced in southwestern Colorado, to designate the shale mass between the Mesaverde (Middle Pierre) and the Dakota. It is a lithological term for use in the field and includes Lower Pierre as well as Niobrara and Benton.

The Colorado interval is represented by marine deposits in by far the greater part of the Cretaceous area, but in New Mexico the isolated coal fields give abundant evidence that the mainland was not far distant, as coarse deposits make their appearance, while farther west in the same state as well as in Arizona and Utah one finds conditions such as characterized the Middle Pierre, marking the strife between land and sea, sandstones and coal beds being the especial features.

The relations of deposits in the southernmost fields of New Mexico are somewhat obscure, the areas being very small and isolated. But there is little room for doubt farther north in the Cerillos and other fields southeast from the San Juan Basin. Lee[99] obtained a detailed section of the Mancos in the Cerillos field. The upper portion is distinctly Pierre and the lower portion, about 2,200 feet, is certainly Colorado in the lower 1,200 feet. One finds here the several subdivisions of the Benton, as recognized east from the Front Ranges, but the limestones of the Niobrara interval have disappeared. A sandstone, Tres Hermanos of Herrick and Johnson,[100]

[99] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 623, 631, 658, 651–654.

[100] C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II., p. 13.

20 feet thick and about 82 feet from the base, is hard, quartzose, cross-bedded and in thin irregular layers, which have rippled surfaces with worm borings and indefinite markings. Of especial interest are impressions very similar to *Halymenites major,* associated with an offshore fauna. At the base of the Benton are conglomerate, 5 feet and carbonaceous shale, 5 feet, with a few inches of coal at the top.

The Tres Hermanos sandstone is 90 feet above the base and only 5 feet thick in the Hagan field, west from Cerillos; though so much thinner, it has the same features. The thin coal bed and its overlying conglomerate, seen in Cerillos, appear to be wanting. A Benton fauna is present in the lower 670 feet of the section. Conditions are practically the same in the Tijeras field. In the Puerco field no coal was seen at base of the Benton, but a conglomerate, 5 feet thick, with pebbles of quartz and chert, recalls that overlying the coal in Cerillos.

In the southwest corner of the San Juan Basin, as Gilbert[101] has shown, the Colorado is represented by mostly sandstones for 180 feet at the base, containing 3 coal seams about midway, while above are 380 feet of carbonaceous and clay shale underlying sandstones and sandy shales. The whole thickness is not far from 850 feet. The coals are not persistent and they were seen in only one section. Elsewhere they are replaced with carbonaceous shale. Winchester[102] says that in the Zuni Mountain region, a few miles south from the locality of Gilbert's section, the Mancos is 60 per cent. sandstone. This sandstone decreases northwardly as do also the coal seams, which disappear in the northern part of the area examined by him.

The Mancos shale is thin in the main portion of the San Juan Basin, the whole thickness, according to Gardner,[103] being not more than 800 feet. Coal seams occur in the upper 500 feet, where the rocks are sandy; there are no coals in the lower part, where clayey beds prevail. The coal seams are usually thin, though occasionally reaching 3 feet, are double or triple and often contain much bone. One seam at times becomes workable, with 3 to 5 feet of sub-

[101] G. K. Gilbert, U. S. Geog. Explorations, etc., Vol. III., 1875, pp. 550, 551.

[102] D. E. Winchester, *Journ. Wash. Acad. Sci.,* Vol. IV., 1914, p. 300.

[103] J. H. Gardner, Bull. 341, pp. 366, 369, 373, 375; Bull. No. 381, p. 462.

bituminous coal which contains much resin. Eastwardly along this southern border no workable seams occur, while farther north along the eastern outcrop only traces of coal were seen. The sandstone decreases in that direction. Lee appears to have found no coal in the Colorado beds along the northeastern border of the basin, but he was able to recognize the Tres Hermanos sandstone.

In Arizona the near approach to the source of sediments is manifest. The most southerly fragment of Cretaceous is the Deer Creek coal field,[104] about 150 miles southwest from the southern termination of the San Juan Basin, near the junction of the Gila and San Pedro Rivers. In the lower or southern part of the field, according to Campbell, 400 to 500 feet of coarse greenish gray sandstone with some shale rest on the Carboniferous limestone. The fossils are imperfect and suffice only to prove Cretaceous age. Three coal seams, much broken and thin, were found in a shaft within the basal 60 feet. The coal is poor; the best has 34.78 per cent. of ash. The Pinedale coal field is about 100 miles north from the Deer Creek area. There Veatch[105] found about 500 feet of deposits containing Benton fossils as determined by T. W. Stanton. The two coal seams are near the base, 10 to 15 feet apart, and are only 25 feet above rocks of Pennsylvanian or Permian age. The seams are 12 and 3 feet thick, but coal from the upper one is very bad, having 54 per cent. of ash. The lower one has some good coal with only 10 per cent. A much more extensive field is that of the Black Mesa[106] in the northeastern corner of the state. The Cretaceous is about 700 feet thick and coal seams were found near the base as well as above the middle. The lower group is within the basal 55 feet and its seams are 7 and 15 feet thick. The upper bed yields a fairly good coal, bituminous and with about 14 per cent. of ash. The lower seam is a worthless mass of shale and coal. The higher beds show numerous seams 2 to 12 feet thick; the coal is evidently inferior, but in default of better material it is used as fuel.

Benton deposits are present in isolated areas within Utah as far west as the 113th meridian along the Arizona border. Almost 45

[104] M. R. Campbell, Bull. 225, 1904, pp. 241–258.

[105] A. C. Veatch, Bull. 431, 1911, pp. 239–241.

[106] M. R. Campbell and H. E. Gregory, Bull. 431, pp. 229–238.

years ago, Gilbert discovered in Washington County a mass of shale about 635 feet thick, including at base a coal group, somewhat more than 130 feet thick, with 5 seams, 4 inches to 4 feet thick. Howell, in Park County, next east, found two coal groups, separated by 500 feet of barren measures, containing Benton fossils. The lower coal group is capped by an oyster bed 1 to 5 feet thick. Thirty-five years later, Richardson examined some small fields in Washington, Kane and Iron Counties.[107] The coal seams are from 50 to 500 feet above the assumed base of the Cretaceous and they are lenses. Ordinarily only one workable bed appears in a section but in some cases there are as many as six. In the Harmony field, only 600 feet of Cretaceous remain, containing 6 seams of coal and shale, 7, 11, 6, 11, 17 and 6 feet respectively, with 4, 5, 4, 7 and 4 feet of coal. At best this coal is very poor, two air-dried samples having 22.89 and 33.96 per cent. of ash. The seams are similarly lenticular in the Colob field. In this field on the North Fork of Virgin River, Richardson saw, at about 100 feet above the basal conglomerate, a coal seam with this structure: carbonaceous shale with fossils; bituminous coal, 2 feet 5 inches; cannel, 5 feet 6 inches. This seam disappeared quickly toward the north, east and southeast; but a similar seam was found at 10 or 12 miles toward the southeast. The cannel at these localities is brownish black with dull greasy luster. The violatile is very high and the hydrogen in dried coal is practically twice as much as that in the ordinary coals. D. White examined it under the microscope and ascertained that its structure and composition are essentially those of high-grade cannel. The Colob coals are better than those of the Harmony field and have from 10 to 15 per cent. of ash. They vary from low grade bituminous to subbituminous. In many cases a coal seam overlies or underlies fossiliferous limestone.

Lee examined a small field in Iron County, north from Washington, where he measured a section of 1,200 feet in which sandstone predominates. The coal seams are in a group of shales and thin limestones, about 150 feet thick, beginning at nearly 800 feet from the basal conglomerate. The fossils are of Benton age. One coal

[107] G. K. Gilbert, U. S. Geog. Explor., etc., Vol. III., pp. 158, 159; E. E. Howell, the same, p. 271; G. B. Richardson, Bull. 341, pp. 379–400.

bed is divided by bands of limestone containing brackish-water mollusks. Another has marine limestone roof and floor, with marine fossils, but one of its partings has *Physa, Planorbis* and other fresh-water forms, related to those of ponds and streams. Several of the sandstones are cross-bedded.[108]

Lupton examined the Emory coal field in in the southern part of Castle Valley, about 40 miles northwest from the Henry Mountains, which had been studied by Gilbert.[109] At approximately 600 feet from the base is the Ferron sandstone, regarded by Lupton as equivalent to Gilbert's Blue Gate sandstone. It is 800 feet thick at the southwest but becomes thinner toward the northeast until at north end of the valley it is but 75 feet. This sandstone holds all the Benton coal seams, but these are confined to the southern part of the valley, disappearing toward the north as the sandstone decreases in thickness. Local unconformities which one must accept as evidence of contemporaneous erosion, occur within this sandstone. The coal-bearing area is a narrow strip about 33 miles long. Fourteen coal horizons were recognized but the deposits are lenticular and correlations are uncertain. The variations are abrupt; in one case, from one to 20 feet within a very short distance. Many of the seams are injured seriously by partings. The coal is low grade bituminous of very fair quality, with color and streak black, and contains resin. In portions it is thinly laminated, but at times the dull layers are several inches thick and resemble cannel.

The most easterly locality in the southern part of the Uinta Basin,[110] at which the Benton coals have been recognized, seems to be that on the Gunnison River about 60 miles east from the Utah-Colorado line. There Lee found at base of the Benton a succession of sandstone and shale with maximum thickness of about 80 feet. The lenses of coal, a few inches to 3 feet thick, occur in the shales. Near the junction of Gunnison and Grand Rivers, 5 deposits of coal, one to 3 feet thick, were seen, but these lenses are too indefinite in extent and contain too much carbonaceous shale to justify mining. The ash in air-dried coal varies from 6 to 34.5 per cent. The sand-

108 W. T. Lee, Bull. 316, 1907, citations from pp. 361–373.

109 G. K. Gilbert, "Geology of the Henry Mountains," 1877, pp. 4–10; C. T. Lupton, Bull. 628, pp. 30, 31, 47–74, 78.

110 W. T. Lee, Bull. 510, 1912, pp. 24, 25, 68.

stones are more or less flinty, are cross-bedded, ripple-marked and locally conglomerate. These coals have been placed in the Dakota by several students, but the presence of fossils confirms Lee's reference to the Benton. The Ferron sandstone cannot be recognized in this part of the basin and the coals of Castle Valley are wanting.

No observer has noted the existence of Benton coals on the northern side of the Uinta Basin within Colorado, but they have been recognized in two outlying fields along the northwestern border in Utah, which have been described by Lupton.[111] The western or Blacktail Mountain coal field is almost due north from the Emery field. The Mancos formation is about 2,650 feet thick. The upper part, 1,450, consists of shale; the middle, about 250 feet, is chiefly sandstone and has coal seams; the lower part is sandstone and shale. The shales increase and the sandstone decreases toward the east: the upper shale is but 800 feet thick in the western part of this field. Four coal seams were seen, 3 to 11 feet thick, but extremely variable. The coal is very similar to that from the Mesaverde, though 3,500 feet lower in the column; some of it is very good, with but 3 per cent. of ash and 10 per cent. of water in the air-dried coal. In the Vernal coal field, 30 miles farther east, the Mancos is not far from 2,500 feet thick, but the upper or shale division is 2,100 feet and the lower or sandy division is about 400 feet, with some coals near the top. It is quite possible, as suggested by Lee, that these coals are at same horizon with those of the Ferron sandstone. They are irregular but in some cases yield a good coal.

The Coalville coal field, about 30 miles northeast from Salt Lake City, Utah, was examined by Wegemann.[112] There, at somewhat more than 1,600 feet from the base of the Cretaceous section at Coalville, is the important coal seam known as the Wasatch. The roof is sandstone, locally conglomeratic, with sometimes a thin shale intervening. It appears to be quite regular. The floor is shale or sandstone and is irregular, there being "rolls" which occasionally cut out as much as 5 feet of the coal. The coal seam is from 5 to 14 feet thick but as a rule, the variations are not abrupt. The coal as mined at Coalville is of excellent quality. It is stated

[111] C. T. Lupton, Bull. 471-*I*, 1912, pp. 13, 35, 44.

[112] C. H. Wegemann, Bull. 581-*E*, 1915, pp. 161–184.

that work was abandoned in one mine because the bed thinned abruptly, the coal being cut out by a "sand roll" or deposit of coarse sand and gravel in the roof of the bed. At about 850 feet below the Wasatch seam, thin coals were seen, which are known as the Spring Canyon beds. The coal is impure and worthless; it is possible that these belong at a Bear River horizon.

The Coalville field is an outlier of the Green River Basin, which is reached in Uinta County of Wyoming near the 111th meridian or nearly 100 miles west from the Utah-Colorado line and probably 25 miles east from the meridian passing through Emory in Castle Valley field of Utah. The relations of the lower part of the section were a source of much perplexity, as the fresh-water fauna had led to the belief that it belonged to the Laramie or possibly even to the Tertiary. Its place in the column was determined by Stanton[113] who showed that it intervened between coarse sandstones and conglomerates below and well-defined Colorado above. Knight[114] recognized an important coal-bearing formation in the southern part of the county, which he named the Frontier. It consists of thick sandstones with coal beds and it may be practically equivalent to the deposits containing the Wasatch seam at Coalville. At a later date Veatch reported upon the southern and Schultz[115] upon the northern part of the county. The thickness of deposits in this area is enormous; Veatch assigns not less than 2,000 feet to the Niobrara, 4,200 to the Benton and 0 to 2,400 to the Bear River. The Frontier sandstone formation, the upper part of the Benton, is about 2,400 feet thick, consists of alternating sandstones and clays, with numerous coal seams. The important coals are the Kemmerer group near the top, consisting of 3 seams within a vertical distance of 90 feet; the highest bed has an extreme thickness of 5 feet, the main Kemmerer is from 5 to 20 feet thick in the mines, but along the outcrop, the variability is much greater, for at some localities between the mines it is very thin, at times absent. At 550 feet below the main Kemmerer is the Wilson bed which is not

[113] T. W. Stanton, "The Stratigraphic Position of the Bear River Formation," *Amer. Journ. Sci.*, Vol. XLIII., 1892, pp. 98–115.

[114] W. C. Knight, "Coalfields of Southern Uinta County, Utah," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542–544.

[115] A. C. Veatch, Bull. 285, pp. 333, 337, 340; A. R. Schultz, Bull. 316, p. 215.

present in the southern part of the field, but is 5 feet 8 inches at Kemmerer, where it yields a coking coal. The Carter bed is 1,300 feet below the Kemmerer and the Spring Valley, 1,475. The last, 5 to 6 feet thick, is apt to be dirty.

The Bear River coals are occasionally thick, as much as 6 feet, but the coal is so dirty as to be worthless. This formation, 2,400 feet on the western side of the county, is only 100 feet at the east side. The Frontier coals are bituminous, of high grade, with low ash and water content; the Coalville coal is subbituminous.

The Frontier sandstone does not outcrop in the Rock Springs field; in northern Carbon County Smith saw it with all the lithological features observed in Uinta County, but without coal. It is 900 feet thick in the southern part but only 500 in the northern part of his district; showing a great decrease toward the east. The Bear River is only 30 feet thick, but this has some thin and worthless streaks of coal. Veatch[116] in the eastern part of the same county found 400 to 800 feet of Frontier, but no coal, while the coaly streaks in shales overlying the Dakota are thin and worthless. Woodruff saw thin streaks of coal, 6 to 8 inches, below the middle of the Colorado, in Park County of Wyoming, almost due north from the Rock Springs coal field. No observer has reported the occurrence of coal at the Frontier horizons at any locality in Montana or in Alberta or anywhere east from the 109th meridian in Wyoming or the 108th in Colorado, but the lowest coal horizon, that resting on the Dakota, reaches to the 105th in Carbon County of Wyoming and, in northern New Mexico, along the southern border, it is present occasionally to near the same meridian. In New Mexico it extends northwardly for only a short distance.

The Dakota.

The Dakota or basal member of the Upper Cretaceous is a sandstone, more or less massive and locally conglomerate in the eastern or Rocky Mountain region. It is often cross-bedded and sometimes ripple-marked. At some localities farther west it contains much conglomerate. The thickness rarely exceeds 200 feet. Land

[116] E. E. Smith, Bull. 341, p. 226; A. C. Veatch, Bull. 316, p. 247; E. G. Woodruff, Bull. 341, p. 203.

conditions existed at few localities and in by far the greatest part of the region no coal occurs. The thin lenses, referred by some writers to this formation, belong rather to the Benton.

The Kootenai.

The Dakota, as described by the earlier students in the Front Range region of Colorado and New Mexico, consists of two sandstones separated by shale of variable thickness. Darton's collections in the Black Hills of northeastern Wyoming proved that the Dakota of that region is complex, that only the upper sandstone is Upper Cretaceous, the other deposits belonging to the Lower Cretaceous. He was convinced that a new name was necessary and offered Cloverly formation as substitute for Dakota. At a somewhat later time Darton, Lee and Stanton discovered somewhat similar conditions in Colorado and New Mexico. In Montana, this formation proved to be practically equivalent to the Kootenai formation of G. M. Dawson, which is important in the Rocky Mountains region within Alberta and British Columbia. This earlier name has been accepted throughout; but in some localities it appears to include the upper sandstone or Dakota. The Kootenai has not been recognized in Colorado and New Mexico west from the Front Ranges except in the Park area of Colorado, where it was seen by Beekly. Elsewhere the "Dakota" sandstone rests on a mass of clays containing some sandstones, the Morrison formation, of which the relations are not wholly clear, though in recent years the paleontologists have shown increasing inclination to regard it as Lower Cretaceous. It has no coal.

The Kootenai is recorded as coal bearing nowhere south from the Black Hills, where Darton gives the succession, as Dakota sandstone, 10 to 100 feet; Fuson shale, 10 to 100 feet; Lakota sandstone, 25 to 300 feet; forming the Cloverly formation of his earlier publications.[117] The Lakota, mainly sandstone, contains the coal. The sandstones are mostly hard, massive, coarse and cross-bedded; but in many places they are slabby, ripple-marked and locally they are conglomeratic. Lenses of coal occur near the base and at times

[117] N. H. Darton, Folios 127, 128, 1905; Prof. Paper 51, 1906, pp. 50–53; Bull. 260, 1904, pp. 429–433; Prof. Paper 65, 1909, pp. 12, 40–48.

attain commercial importance. Two are near Aladdin, one of them, 2 feet to 3 feet 6 inches, the other, 10 feet above, being thinner. The extreme thickness is at a little way north from Aladdin where the lower lens becomes 8 to 9 feet; but both thin away, being replaced with impure coal, before disappearance. The coal at Aladdin is soft and bituminous, as it is also at Sundance. In the Cambria district, on southwest side of the region, there is an oval space of about 10 square miles, in which the coal averages 5 feet, but, in the surrounding area, the thickness decreases, the coal becomes impure and carbonaceous shale replaces it. On the southern slope of the Black Hills, a coal bed, 5 feet thick near Edgemont, is distinctly local; it quickly disappears toward the southeast, giving place to sandstone; while toward the northwest, it becomes merely a coaly shale. There is little coal on the easterly side of the Black Hills, only thin lenses of coal and coaly shale were seen, and these are confined to the northerly portion. The thick bed near Aladdin has a bone parting somewhat more than one foot thick, which, in appearance, closely resembles cannel; it has 38.69 per cent. of ash. The upper part of the Lakota holds much petrified wood; cycad stems are numerous at several localities.

Darton recognized his Cloverly formation on both sides of the Bighorn Mountains in north central Wyoming, where, in much of the region, the Dakota sandstone appears to be wanting. Streaks of coal were seen occasionally in the Lakota, but they offer no promise of economical importance. Fisher[118] saw Lakota coal in the drainage area of No Wood creek at the westerly base of Bighorn Mountain. It is less than 50 feet above the Morrison formation and is found within a considerable area. One opening was in a bed divided by a parting of 2 inches into benches, each 4 feet; but the coal is a lens and thins away rapidly on all sides. The coal is dark with dull earthy luster, conchoidal fracture and resembles carbonaceous shale; but it is bituminous coal with not more than 11 per cent. of ash. Fisher suggested that the formation might be Dawson's Kootenai. No coal was seen by Woodruff within the southwestern part of the Bighorn Basin and the formation appears, according to Darton, to be barren in central western Wyoming, but

[118] C. A. Fisher, Bull. 225, 1904, pp. 355, 362.

coal, too thin to be worked, was found by Washburne in the northeast part of the Bighorn Basin near the Montana line.[119]

Calvert reports that, in the Electric coal field, Park County, Montana, the Kootenai is 577 feet thick and with same general structure as that of the Cloverly. The Fuson, 230 feet, consists of variegated shales, limestones and thin sandstones; the Lakota, 249 feet, has a coal bed, one foot thick and underlying a conglomerate sandstone; but it seems to be local. In the Livingston coal field of the same county, the Kootenai is 540 feet thick and apparently has no coal. In the Crazy Mountains coal field of Meagher County, north from Park, Stone found the Kootenai only 235 feet thick with variegated sandstones in the upper half and variegated shales in the lower half. The lowest of the sandstones is coarse and has layers of conglomerate; it overlies one foot of black shale; no coal is reported.[120]

Calvert[121] found 512 feet of Kootenai in the Lewistown coal field of Fergus County, where the upper part is variegated shale with two massive, cross-bedded sandstones, 8 and 25 feet thick; the lower part, 147 feet, is coarse sandstone, locally conglomerate, with sandy shale. The workable coals of the Kootenai in this field are in the lower portion at 60 to 90 feet above the base and underlie a massive cross-bedded sandstone. In some districts only one seam is present but in others there are several. The seams are distinctly lenses, separated by unproductive spaces. The thickness seldom exceeds 5 feet and ordinarily the coal is divided into benches by partings of shale or bone. The roof is shale or sandstone and the floor is shale or clay; in many cases a bench-bone is at top or bottom of the coal. A dull, lusterless coal, resembling cannel, was seen at several places but especially in the Mace mine, where it occurs as lenses within the coal, the largest being 200 feet long. The coal is accepted as bituminous, but the percentage of ash varies greatly.

The Great Falls coal field in northern Cascade County, west

[119] E. G. Woodruff, Bull. 341, p. 203; C. W. Washburne, the same, p. 170; N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, pp. 447–449.

[120] W. R. Calvert, Bull. 471-*E*, pp. 34, 53, 58; R. W. Stone, Bull. 341, p. 80.

[121] W. R. Calvert, Bull. 341, pp. 110, 113, 117, 119; Bull. 390, pp. 56, 61, 72, 74.

from Fergus and north from Meagher, was examined by Weed and afterward by Fisher.[122] The Kootenai, 400 to 500 feet, according to Fisher but about 750 according to Weed, was formerly regarded as Dakota; but J. S. Newberry in 1887, cited by Weed, determined that it is Kootenai. The Dakota was not recognized. The individual deposits are inconstant, sandstones and shales alike being lenses. The coal horizon is about 60 feet from the base and the seams are clearly lenses. Weed has described the coals in detail. The great coal seam, with extreme thickness of 12 feet in Sand Coulée district, splits toward the west into two beds, which, where last seen, were separated by 25 feet of shale. The seams are usually divided and the benches often differ in quality of the coal, coking and non-coking being found within the same bed. Picked samples from one bed had barely 10 per cent. of ash, but one from the middle part of the bed had 27 per cent. Official samples, collected by Fisher, give from 16 to 23 per cent. of ash. As in sampling of the coal, nothing is taken which ought to be removed in mining, it is certain that this fuel, as it reaches the consumer, must be decidedly inferior in quality.

Stebinger[123] gives about 2,000 feet as the thickness of Kootenai in the Teton coal field, which, like the Great Falls field, is near the western boundary of Cretaceous deposition in Montana. The formation is practically without coal, there being only some black shale with 6 or 8 inches of coal.

The Kootenai shows great variation in thickness within Alberta. Dowling,[124] summarizing observations made by himself and others in various parts of the province, states that the maximum deposition was near the axis of the Rocky Mountains, where the base is a great bed of sandstone, succeeded by sandstones and shales with many seams of coal. In the Elk River escarpment, it is 3,600 feet, but at Blairmore, toward the east, it is but 750; northward, near Banff, it is 3,900 feet, but in Moose Mountain, east from the main range, it is only 375 feet. Farther east, the formation is unim-

[122] W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 3, 1892, pp. 302, 303, 313–321; C. A. Fisher, Bull. 356, 1909, pp. 22, 50, 51, 52, 77, 78.

[123] E. Stebinger, Bull. 621-*K*, 1916, p. 124.

[124] D. B. Dowling, Geol. Survey Memoir, 53, 1914, p. 27.

portant owing to thinning of the beds; it has not been recognized in Manitoba.

In Alberta, the Kootenai is fully exposed only in the more disturbed portion of the Rocky Mountains area and the more important coal deposits, for the most part, are west from the Mountains in British Columbia. Mackenzie[125] measured about 700 feet of Kootenai on Oldman river in southern Alberta, in the Foothills region. The rocks mostly arenaceous. An overlying sandstone formation was assigned to the Dakota. A Coal Measures group, about 200 feet thick, is in the upper part of the Kootenai, where the sandstones increase in coarseness. Near Blairmore, five coal seams were examined; the total is about 40 feet, but two of the beds are poor and shaly; elsewhere the quantity of coal is less.

The Crowsnest coal field[126] is farther west, in and beyond the Mountains, and the greater part is in British Columbia. In Crowsnest pass, within Alberta, McEvoy gives a section of 4,736 feet, which he regarded as wholly Kootenai. The coal bearing portion begins at 1,170 feet from the base and is 1,847 feet. The coal is 198 feet, somewhat less than in the main field farther west. McLearn[127] states that the lower part of the Kootenai in this region contains abundant remains of plants and erect stems of trees.

Dowling[128] examined a small area of Kootenai on the North Saskatchewan river, about the 55th degree and near the 118th meridian. There, behind the Brazeau Hills, he saw 5 coal seams within a vertical distance of 631 feet. The lowest and highest, with somewhat more than 12 feet thickness, yield worthless coal, but the second and third, with about 23 feet of coal, are good, though the ash is rather high, being from 12 to 15 per cent.: the grade is semibituminous.

Malloch[129] reported upon an extensive district farther west, on the headwaters of the Saskatchewan, Bighorn and Brazeau Rivers, and within the outlying ridges of the Rocky Mountains. The thickness of Kootenai is 3,658 feet, which is unexpectedly great, as

[125] J. D. Mackenzie, Summ. Rep. Geol. Survey, Canada, pp. 239, 243, 244.

[126] J. McEvoy, Ann. Rep., Vol. XIII., 1900, Pt. *A*, pp. 84–88.

[127] F. H. McLearn, Summ. Rep., 1915, p. 111.

[128] D. B. Dowling, Summ. Rep. for 1913, pp. 150, 151.

[129] G. S. Malloch, Memoir 9–2, 1911, pp. 25, 31–33, 52, 53, 59, 60.

farther south in the foothills the formation is thin. In the basal 700 feet, there is a ripple-marked sandstone as well as shales and sandstones with impressions of rain drops. Sandstones and shales are irregular throughout and clear evidence of contemporaneous erosion was observed at several localities. Some thin beds of conglomerate were seen but they are indefinite and are clearly local.

Twenty-one coal seams were seen in a section of 2,760 feet, from 2 inches to 9 feet thick; in another section of about 1,100 feet in the upper part of the formation, 7 seams were seen, with total thickness of about 26 feet, while in a third of nearly 1,300 feet, there are 8 seams with total thickness of more than 52 feet, besides other seams less than 3 feet thick. Comparison of the sections make clear that the seams are lenticular. The coal throughout is bituminous and, with rare exceptions, is coking. The quality is excellent, ash and sulphur being low.

Malloch thinks that the shales, sandstones and conglomerates are of fluviatile origin. Absence of roots in the floor of coal seams leads him to suggest that these may have developed in bogs within choked oxbows or on coastal plains. The quantity of coal decreases rapidly eastward from the mountains.

Some Chemical Features of Cretaceous Coals.

No substance resembling the pyropissite of Sachsen has been mentioned by any observer, the only allied material being that seen by Dunker in the Hannover region, which he thought might be hatchettin.. Resin of one sort or another occurs commonly; it is termed Bernstein, retinite, walchovite or simply resin by various authors. It is in grains or in lumps several inches long in the Lower Quader coals of Bohemia and Moravia; at one locality in Hungary it is so abundant as to give the local name to a coal seam; there is much in New Zealand; in North America, resins are characteristic features of coals in the Laramie, the Fox Hills and the Pierre as well as in those of the Benton. The color is from honey yellow to dark yellow and according to Thiessen is rather darker in the Fox Hills coals of northern Colorado than in the Eocene coals of the Dakotas. Resins appear to be wanting in bituminous coals of

high grade; at least, no note is made anywhere respecting their existence in such coals.

Cannel has been reported from numerous places. Often it evidently is little more than highly carbonaceous mud, forming a faux-toit, faux-mur, or a thick parting, which may be regarded as roof and floor to the benches which it separates; but typical cannel is by no means rare. A great cannel lens was seen by Hector and by Campbell in one portion of the Buller coal field in New Zealand and Denniston has referred to what are clearly localized cannel deposits in coal beds. Hector has given the proximate analysis of the lens as water, 6.20; ash, 3.60; volatile matter, 61.41; fixed carbon, 38.58. Within the United States and western Canada, cannel has been described from Laramie, Benton and Kootenai horizons.

Cannel was discovered in the Benton of the Colob field, Utah, by Richardson, whose description shows that it is the lower bench of at least two lenses occurring at the same horizon. The material was studied microscopically by D. White, who recognized it as a typical cannel. At a later date it was studied in detail by Thiessen,[180] who reported that it has the appearance and characteristics of cannel. Under medium enlargement, the coal is a dark, homogeneous mass, in which are embedded resinous particles, dark and light, with some large spore exines and cuticles, this embedded material comprising about one half of the whole. Under higher power, the enclosing material is shown to be like the "groundmass" of other coals, being in largest part a mass of closely packed very thin flattened particles, most of which are spore and pollen exines, with small fragments of cuticles. In great proportion, these are fragmentary and many are so macerated that they are unrecognizable; but even in this condition, the color and optical action are the same as in the recognized cuticles and exines. As all intergradations are present, he thinks it reasonable to conclude that the origin is the same. With this is the amorphous substance or binding material as in the débris of lignite. The darker resinous substances are the more abundant and, in color as well as in appearance, they resemble those of lignite. Many are cylindrical, having retained the shape of resin cells in the wood. Smaller particles enter into the

[180] R. Thiessen, "Origin of Coal," 1914, pp. 244, 245.

groundmass. The darker resins are deep brown in color and in general are opaquely glassy. The lighter resins are in striking contrast and tend to be more irregular in form. Besides charred cell fragments, few other bodies are present and none of them is in recognizable condition. In variety of constituents, this coal is very simple and thus approaches Paleozoic cannel very closely. It is so brittle that proper sections cannot be prepared. The analysis showed 67.61 of volatile matter and 32.39 per cent. of fixed carbon in the pure coal. The cannel is overlain by a thin bituminous bench, which has 60 per cent. of volatile to 40 of fixed carbon, making probable that the upper bench contains much spore material.

Cannel is said to be present in the Lakota sandstone of the Black Hills, at a Kootenai horizon, where it is in two benches, each about a foot and a half thick and overlain by bituminous coal. The proximate analysis suggests that this is more probably a bony coal, as the volatile is but 38.64 and the fixed carbon 61.46 per cent. in the pure coal; the ash is 24.16. Cannel is present in the Kootenai of the Elk River district of Alberta, the composition being 65.55 of volatile and 34.45 of fixed carbon; the ash is only 9.86 per cent.[181]

That coals of very different types may occur in the same vertical section is evident from conditions in the Wealden of Hannover. Dunker[182] states that in many localities the coal resembles the older black coals, there being no trace of woody structure and the streak is blackish brown. This type of coal was analyzed by Regnault; but lignite is present also, which preserves the woody structure and has reddish brown streak. A sample from Helmstadt was analyzed by Varrentrapp. The results are:

	C.	H.	O and N.
I.	89.50	4.83	4.67
II.	73.50	5.18	21.30

Beside these there is the Blätterkohle, composed of leaves and twigs of conifers and cycads, which is so little changed that the leaves become flexible when soaked in water. This type occurs in the same

[181] U. S. Bureau of Mines, Bull. 22, 1913, p. 194; D. B. Dowling, Geol. Survey of Canada, Memoir 53, 1914, p. 74.

[182] W. Dunker, "Monographie," etc., p. xiii.

vertical section with other coals, some of which are of the "black" type. No analysis of the Blätterkohle is given. Dunker conceives that the black coal was formed from lycopods and ferns, as no remains of other plants have been found in it; the lignite, however, seems to him to be composed of conifers, cycads, lycopods and ferns. The ash of the Wealden coals in Hannover, according to analyses made by Saurwein and published by Zincken,[183] appears to average high, for in most cases the percentage exceeds 13.

Cžjžek[184] has described the black coal with black brown streak mined near Grünbach in Lower Austria, which occasionally contains fragments of branches, retaining their form but showing no trace of fiber. This, belonging to the Upper Cretaceous, is a lignitic coal, for, as analyzed by Schrotter, it has carbon, 74.84; hydrogen, 4.60; oxygen, 20.56. The water and ash are very low. The important coals of Hungarian Cretaceous are in the middle or fresh-water formation consisting of marls and coal beds. Hantken presents no detailed analyses; the water and ash, for the most part, are less than 10 per cent.

The Cretaceous coals of Queensland are rarely thick enough to be workable; they occur as lenses scattered over a great area. The analyses reported by Jack[185] are all proximate; reduced to pure coal for fixed carbon and volatile they show:

	Water.	Ash.	Volatile.	Fixed Carbon.
I	7.16	36.53	37.22	62.77
II	8.25	19.02	41.82	58.17
III	0.33	30.20	43.37	56.62
IV	2.32	9.65	17.26	82.73
V	8.30	2.80	42.26	57.73

The coal of No. V., belonging in the Lower Cretaceous, cokes well. The stratigraphic relations give no explanation for the low volatile of No. IV. There is no relation between ash and volatile, for the ash of III. is almost ten times that of V., but the volatile is almost the same in both coals.

183 C. Zincken, "Erganzungen zu der Physiographie der Braunkohle," Halle, 1871, pp. 4, 5.

184 *Jahrb. k. k. Reichsanst.*, Vol. II., Part 1, p. 144.

185 R. L. Jack, "Geology of Queensland," pp. 398, 532, 537.

The analyses of New Zealand coals are proximate. Hector has published those of samples taken from different parts of two important seams:

	Water.	Ash.	Volatile.	Fixed Carbon.
I.	13.93	7.16	46.85	53.15
II.	16.46	7.20	33.45	66.54
III	4.98	1.19	41.89	58.10
IV.	10.38	0.98	38.36	61.63

The difference in volatile of I. and II., from the same bed, is unusually great. Cox has given the results of numerous analyses of coals from the Buller field; the coal is bituminous and that from some mines is caking. The water content is very low, seldom exceeding 7 per cent. The ash is amazingly small, there being less than one per cent. in 9 of the 14 samples and only 4 exceed two per cent. Analyses of coals from Otago, as reported by Hutton, have in most cases very little ash. One cannot resist the suggestion that the samples may have been selected "average" lumps.[186]

Many thousands of analyses of coals have been made by the United States Bureau of Mines and a great number have been made for the Geological Survey of Canada. The samples consist of cuts across the whole bed, omitting such partings or benches as should be removed before shipment of fuel from the mine. For the most part, the samples have been taken from mines in successful operation or, if the region be undeveloped, from such seams as gave promise. The purpose of the sampling is to determine the commercial value of the property and the method is beyond doubt the best yet devised. But the student of geological relations should read the descriptive portion of Bulletin 22 in order to learn how far the analyses concern matters occupying his attention.

The Laramie coals. The Laramie formation, as defined in preceding pages, contains at most localities only thin seams of coal; but in the northern part of the San Juan Basin of New Mexico and Colorado as well as in the Edmonton region of Alberta, the

[186] J. Hector, New Zealand Reps. for 1871–2, pp. 132, 134; J. H. Cox, the same, for 1874–6, p. 25; F. W. Hutton, "Geology of Otago," 1875, pp. 101, 105, 110.

seams become thick and of economic importance. Two analyses of the great Carbonero seam have been published, I. near Fruitland, where the seam consists of bone, shale and coal, 12 feet, and at base 5 feet of coal, which was sampled; II. near Pendleton, where the thickness is 48 feet, but only 7 feet were included in the sample.

	Water.	Ash.	Volatile.	Fixed Carbon.	Sulphur.
I.	9.89	10.19	48.10	51.90	0 80
II.	8.30	8.25	42.61	57.39	0.80

The Edmonton coals are subbituminous and break up on exposure; but this disintegration is much less rapid if the fuel be stored under cover. Dowling has reported the results of numerous analyses, which show no serious variation in composition of the pure coal; it suffices to cite three from the upper group, which includes the great seam on Pembina River, and one from the Clover Bar group several hundred feet lower in the section.

	Water.	Ash.	Volatile.	Fixed Carbon.
I.	12.93	10.00	41.46	58.52
II.	13.78	6.86	40.33	59.66
III.	11.78	3.31	45.58	54.42
IV.	17.28	7.30	47.30	52.70

Coals of the Clover Bar group appear to be less advanced in conversion than those of the higher group; three samples from different mines yielded 43, 45 and 47 per cent. of volatile. The ash rarely exceeds 8 per cent.[137]

The Fox Hills coals. The coals taken by the writer to be of Fox Hills age are irregular but they are better than those of the Laramie, within the United States; and in some extensive areas they are of great economic importance. Along the eastern base of the Front ranges, these coals are mined on large scale in several fields from New Mexico almost to the Colorado-Wyoming line; in much of the region the seams are broken more or less by bony partings, but these are separated readily and they have not been included in the samples taken for analysis. Of the analyses, Numbers I. to V. are

[137] U. S. Bureau of Mines, Bull. 22, p. 141; D. B. Dowling, Memoir 53, pp. 11, 18, 21, 47.

from the Raton-Trinidad field; VI. and VII. are from the Canyon City field; VIII. and IX. from the Boulder District; and X. is from Platteville, about 40 miles north from Denver.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 3294...	2.72	14.57	38.51	61.49	0.83	84.58	5.54	7.64	1.41
II. 3295...	3.45	16.67	40.14	59.86	0.91	83.62	5.77	9.06	1.55
III. 6595...	2.45	17.40	34.36	65.64	0.96	85.32	5.67	6.93	1.12
IV. 115D..	2.25	20.44	38.15	61.85	0.82	84.08	5.61	8.02	1.47
V. 7196...	3.88	13.73	33.18	66.82	0.57	84.56	5.34	7.97	1.56
VI. 6254...	9.89	6.21	42.05	57.95	0.52	76.30	4.77	17.33	1.08
VII. 6376...	5.44	12.10	46.12	52.88	0.87	77.67	5.96	14.18	1.32
VIII. 1523...	18.68	5.99	46.30	53.70	0.73	76.28	5.30	16.16	1.53
IX. 6836...	17.32	4.64	41.06	58.94	0.39	74.97	5.18	18.00	1.46
X. 6408...	28.90	5.02	43.63	56.37	0.70	73.19	5.19	19.51	1.41

The ash is high at the south, but the seams in the lower part of the Vermejo group yield a fuel so good for steaming purposes that the high ash becomes unimportant; the ash decreases northwardly and in the Boulder District it is about that of an ordinary good coal. But in the same direction the type of coal changes; in the Raton-Trinidad field, one finds usually a high-grade bituminous coal, that from some extensive mines yielding a strong coke; in the Canyon City field, the coal is still bituminous, but it does not cake and the oxygen is about double that in the Trinidad coals; in the Boulder District, the coal is distinctly subbituminous, is xyloid in appearance and disintegrates on exposure. There are no such violent contrasts between proximate and ultimate composition, such as have been recognized in some of the newer coals.

The Fox Hills as a coal-bearing formation is important in southwestern Wyoming; the Adaville seam of Uinta County has maximum thickness of 84 feet; at least a part of the Black Buttes coal group in Sweetwater County belongs here; the coal assigned to the Lewis in Carbon County is taken by the writer to be at a Fox Hills horizon. The seams become thin and unimportant eastwardly. The Adaville seam yields coal of almost the same composition at two widely separated mines, which differs little from that of the Boulder District in Colorado. The volatile in the coals of Uinta and Sweetwater Counties varies from 38 to almost 49 per cent., though in the coals compared the carbon is almost the same throughout The

lowest percentage of carbon in either county is barely 73; usually it is somewhat more than 76 per cent. These coals are high in water but not in ash. They are classed as subbituminous and are not held in high esteem as better fuel from the Pierre is readily accessible.[188]

The Pierre coals. These attain great importance in the San Juan, Uinta and Green River Basins as well as in portions of Alberta in Canada. There are few localities whence coal, positively recognized as Lower Pierre, has been taken for official analysis. Probably the Hagan coal of Sandoval County in New Mexico belongs here, but the only available analysis is proximate. The Upper Pierre or the Lewis and the Bearpaw shales have no coal deserving consideration. The Middle Pierre or Mesaverde, as originally defined, is the productive formation. Its coals are mined in the Cerillos coal field, where all grades from bituminous to anthracite are obtained; and in various parts of the San Juan Basin. Of the analyses given here, I. and II. are from the Cerillos field, III. and IV. are from the southern part of the San Juan Basin, V., VI. and VII. are from the northern part.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 6153........	5.70	5.99	2.47	97.53	0.78	93.84	1.99	1.96	1.34
II. 6154........	3.76	4.89	37.07	62.83	0.62	82.49	5.78	9.86	1.25
III. 1307........	10.79	18.66	47.94	52.06	1.79	78.06	5.70	13.10	1.35
IV. 1278........	12.29	6.99	42.84	57.16	0.78	78.43	5.51	14.00	1.28
V. 5761........	1.71	6.92	39.68	60.32	0.71	82.50	5.50	9.58	1.71
VI. 2121........	3.04	9.66	44.70	55.30	4.03	81.01	5.99	7.27	1.70
VII. 537D.......	1.24	16.12	38.30	61.70	0.66	84.64	5.56	7.49	1.65

The sample III. consisted of slack and VII. represented the run-of-mine. II. and VII. yield a high grade coke. The anthracite of Cerillos is believed to be due to a sheet of andesite overlying the seam.

The Mesaverde coals of the Uinta Basin are in two groups, separated by a thick sandstone. The upper group, the Paonia shales, has many coal beds of which one or more may be workable at a given locality; the lower group, Bowie shale, contains important seams. In the southeastern part of this basin, the Paonia and Bowie cannot

[188] Bull. 22, pp. 137, 138, 69, 58, 59, 54, 55, 82 for Colorado-New Mexico; pp. 310, 319 for Wyoming.

be distinguished; yet in the western part the coals differ altogether. The Paonia coals are subbituminous, with 15 to about 20 per cent. of water, almost 17 of oxygen and less than 76 of carbon; whereas the Bowie coals have less than 4 per cent. of water, 9 to 12 per cent. of oxygen and from 79 to 83 per cent. of carbon. The Paonia coals are at times rather high in ash, but the coal mined from the Bowie is uniformly clean, the ash rarely exceeding 6 per cent.

The Mesaverde coals are important in Sweetwater County of Wyoming, within the Green River Basin. There, as in the Grand Mesa area within the Uinta Basin, the coals are in two groups, Almond and Rock Springs, which are separated by a greater interval than the Paonia and the Bowie. The Almond coals are lower in water than are those of the Paonia, but the oxygen is higher while the carbon is from 72 to 76 per cent. The Rock Springs coals have about 5 per cent. less of oxygen and the carbon varies little from 79 per cent. Farther north in Wyoming, within the Bighorn Basin, a coal is mined near Cody which has 21 per cent. of oxygen and only 71 of carbon.[139]

In Montana, the coal seams are more irregular than in southern areas, the lenses, for the most, are of less extent and the coal is apt to be dirty. The Judith River seams, or approximately the Upper Mesaverde, are of subbituminous coal with water from 10 to 25 per cent., 16 to 20 per cent. of oxygen and 72, 73 to 76 per cent. of carbon. But the coals of the Eagle sandstone are bituminous with 12 to 16 of oxygen and 76 to 80 per cent. of carbon. The ash usually is high, 13 to more than 16 per cent.

Dowling has published many analyses of Belly Rivers coals from Alberta. They are proximate but they represent a great number of localities The water rarely exceeds 5 per cent. in the Foothills region but in the Lethbridge-Medicine Hat region it increases eastwardly and, near Medicine Hat, it is about 20 per cent. The ash in beds of workable thickness is low, seldom exceeding 8 per cent. According to two analyses of Lethbridge coal, published by Stebinger,[140] that fuel is on the borderland between subbituminous and

[139] U. S. Bureau of Mines, Bull. 22, pp. 67, 140, 141 for San Juan Basin; pp. 55, 56 for Uinta Basin; pp. 313, 315, 316 for Green River Basin.

[140] E. Stebinger, Bull. 621-*K*, 1914, p. 138.

bituminous, but it is of better quality in respect of ash than the Montana coals at the same horizon.

The Benton Coals.—The published reports contain no reference to occurrence of coal in deposits representing the Niobrara time interval; the coal seams are associated with rocks containing Benton fossils. These coals are confined to the western part of the Cretaceous area within Arizona and Utah, though extending eastwardly for a short distance into New Mexico, Colorado and Wyoming. The coal in Arizona and New Mexico is rather high in ash, about 14 to 16 per cent., and the sulphur seems to be not far from 2 per cent., so that it is an inferior fuel. Analyses I., II. and III. are from Iron County, Utah, where the coal seams are often closely associated with marine limestones; IV. is from Emery County, where the coal is mined extensively; V. and VI. are from Uinta County, on the northwest side of the Uinta Basin.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 5494....	4.93	13.04	45.40	54.60	8.19	76.82	5.56	8.29	1.14
II. 5304....	10.35	9.82	45.39	54.61	7.27	76.52	4.97	10.05	1.19
III. 5305....	14.19	9.92	44.00	56.00	7.10	72.83	4.77	14.18	1.12
IV. 12627....	4.00	5.93	45.4	54.6	0.44	81.01	5.64	11.52	1.39
V. 5510....	8.82	6.25	43.10	56.90	1.95	76.67	5.58	14.52	1.19
VI. 5513....	8.21	11.79	42.87	57.13	2.20	76.28	5.60	14.70	1.22

The carbon is highest at the west in Iron County, being more than 83 per cent. in the pure coal of I.; it is 78 in the pure coal of III., 81 in that of II. and 81 in the best coal from the Emery coal field. The sulphur in Iron County is so abundant as to suggest contribution by animals. V. and VI. are the upper and lower benches of a single bed and show improved conditions during formation of the upper bench. Lee has given analyses of the upper and lower benches of a bed in Delta County of Colorado; the upper bench has 6 per cent. and the lower bench 22 per cent. of ash. There, as in the Uinta County seam, the lower bench, though richer in ash, is poorer in volatile. The Frontier coals in Uinta County of Wyoming, in the Green River Basin, have excellent fuel in several of the seams. They are bituminous, low in ash and sulphur and have from 77 to almost 81 per cent. of carbon.[141]

[141] Bureau of Mines, Bull. 22, pp. 47, 139; for Utah, pp. 80, 193, 194; C. T. Lupton, Bull. 628, p. 80; W. T. Lee, Bull. 510, p. 201.

The coals of Dakota age are insignificant. The only ultimate analysis shows that in one case, at least, the coal is high-grade bituminous but with notable percentage of ash.

The Kootenai is without coal south from the northern border of Wyoming and there as well as in Montana the coal is not of high grade. In the Black Hills of Wyoming one finds extensive mines at or near Aladdin. In one of those the water is from 14 to 18, the ash from about 5 to 16 and the sulphur from 5 to 7 per cent., all in freshly mined coal. Within Montana, the Kootenai coals become important locally and are mined at many places in Cascade and Fergus Counties. In the former county, the water is but 3.5 to 7.5 per cent. but the ash is from 14 to 21. Sulphur is less than 3 per cent. The coal is bituminous, the carbon in pure coal being about 80 and the oxygen, barely 15 per cent. In Fergus County, the ash within several districts is from 10 to 17 per cent. of the air-dried coal; but only 3 out of 10 samples gave more than 10; the sulphur, however, is much greater than in Cascade, being 5 per cent. and upward. The percentage of carbon in pure coal is from 80 to 85 and that of oxygen 9 to 15. But one analysis shows only 75 of carbon with 19 of oxygen.[142]

The analyses published by Dowling[143] show regional variation in the coals of Alberta. The ash is highest in areas near the mountains, where three districts have 13 to 22, 10 to 20 and 8 to 17 per cent. In all other areas, it rarely exceeds 8 and is usually about 5. The water is about 3 per cent. Sulphur is in small quantity, there being one extensive region with barely a half per cent. The coal is bituminous and often is caking. Anthracite is obtained in disturbed districts.

In reading the results of analysis as given above, one is in danger of concluding that "clean" coal is the rule and "dirty" coal the exception. Emphasis must be laid on the fact that samples for analysis have been cut, for the most part, from mines in successful operation or from promising exposures. Lenses yield the best coal in the central portions; toward the borders, their coal becomes dirty and usually passes into carbonaceous shale. In many vertical sec-

[142] Bull. 22, pp. 305, 126, 127, 130–133.

[143] D. B. Dowling, Memoir 53, pp. 74–79.

tions, one observes that a large proportion of the seams are "dirty," and in reading descriptive notes of seams from which samples were taken, he finds that only in rare instances is a seam, upwards of 3 feet thick, clean throughout, while of thicker seams, a half or more must be rejected in sampling. Even in thinner seams, selection of samples requires no little skill. The testimony of observers, cited in preceding pages, proves that a very great part of the Cretaceous coal was formed amid conditions unfavorable to accumulation of clean coal. Generally speaking, foreign materials are in partings, but occasionally the mineral matter is distributed throughout so that it cannot be removed by washing.

SUMMARY.

The facts recorded in preceding pages may be grouped to make clear their bearing upon the matters at issue.

1. *The Distribution of Coal.*—One who reads reports covering an extensive area is liable to believe that caprice has determined the distribution of coal. The presence of coal at one locality gives no assurance that it will be found at the same horizon in others, for great barren spaces exist between productive areas, so that individual seams appear to have small areal extent; apparently, the total area on which coal was accumulating at any time was a comparatively insignificant part of the whole. There is, however, an evident relation between occurrence of coal seams and the prevailing character of the sediments, which would justify the assertion that in one locality coal may be present, and that in another it is almost certain to be absent. The descriptions seem to prove that coal seams accumulate only under conditions such as mark great river or coastal plains, where intervals of relatively rapid subsidence were followed by others, during which subsidence was slow; finer materials were deposited upon the coarser and coal accumulation began. But where the deposits are fine, such as those laid down at a notable distance from the source of materials and under a practically constant cover of water, coal is not present.

The relations are sufficiently clear in the Upper Cretaceous of Europe. Coal is of rare occurrence in England, France and western Germany, where the deposits, almost without exception, are

marine and largely calcareous; but in a part of France, the closing stages are characterized by thick fresh-water deposits and thin seams of lignitic coal have been observed. Land deposits abound in eastern Germany and there coals are found, which at times attain economic[144] importance. The Hastings Sand of England, at base of the Wealden, is thought to be a delta deposit; if so, the areas remaining may mark, in greatest part, the submerged portions, as they contain no coal and the sand holds much driftwood. This formation has been recognized in France, where within small areas, some coal seams exist which have been mined. The Wealden is exposed within a large space in Hannover, reaching westward from the Harz Mountains to the Holland border, where it underruns newer formations. At this western limit, the deposits are fine clays or marls with important limestones, but no coal. Coarse deposits are reached farther east and with them the coal. The seams are usually thin and irregular, but occasionally one is more than 5 feet thick. In a section, toward the west, where shale, more or less argillaceous, predominates, a workable seam occurs, but it is associated with the principal sandstone of the section. The coals of New Zealand and Queensland either rest on sandstone or are separated from it by thin clay or shale.

The immense area of Cretaceous in the United States and Canada affords ample opportunity for comparisons. Each formation, with possible exception of the Niobrara, is coal-bearing. The chief source of detritus was at the west, though important contributions were received from the southern border, which probably lay in northern Mexico, not far from the international boundary.

The Laramie marks the closing stages of the Cretaceous and, where the succession is complete, deposition appears to have been continuous into the Eocene. Except in a portion of Alberta, where a brackish-water fauna is found, the rocks are of continental type; leaves abound in many beds and the animal remains are of river or pond forms. The conditions recall those observed on the great

[144] It should be noted that this term, "economic importance," has not the same signification everywhere: in the United States, a coal seam, less than thirty inches thick, is not thought to be workable, except in localities without railway communication. On the continent of Europe seams very much thinner have been worked.

plains of China. The drainage appears to have been irregular and shifting, the deposits are variable in form and composition, and except in a few localities, widely separated, the coal seams are thin. The periods, during which coal accumulation was possible in any locality, were usually brief; but in the northern part of the San Juan Basin, one seam attains the thickness of 100 feet and in the Edmonton district of Alberta the seams are not only thick but, unlike the seam in the San Juan, they yield coal of excellent quality.

The Fox Hills, underlying the fresh-water Laramie, is recognizable as a persistent sandstone with intercalated shales and coal seams. It resembles a low-lying strand of vast extent, frequently invaded for considerable periods by the sea, so that it has an offshore fauna, which is of strangely persistent type. This is passage from the continental conditions of the Laramie to the marine conditions of the Pierre. The coal seams, yielding better fuel than that from the Laramie seams, are thin and variable at most localities, but at times in considerable areas, some of them become thick and of great economic importance. Merely insignificant seams occur in the San Juan Basin except at the north, where two, 4 and 12 feet thick, are present in the shales immediately overlying the Pictured Cliffs sandstone. In the Green River Basin, the Adaville seam has a maximum thickness of 84 feet, but the seams become thin eastwardly and there are great spaces in which the formation seems to be barren. In central and eastern Wyoming as well as in Montana and Alberta, only occasional exposures of coal have been reported and those are unimportant. In the basins along the eastern foot of the Front Ranges in New Mexico, the seams are numerous and some horizons are extremely productive along this line of more than 300 miles; but the individual seams are variable to the last degree in thickness and quality, there being many spaces where the coal is either wanting or worthless.

The Pierre at the west and southwest is, for the most part, a mass of sandstone and sandy shale; toward the east, it becomes shale at top and bottom, while Middle Pierre or Mesaverde persists as a wedge of sandstone and shale thinning eastwardly until it becomes replaced wholly with fine shales and irregular limestones. This wedge thins away unbroken in Colorado and New Mexico but

in Montana it is divided by shales into subordinate wedges, and these "fingers" disappear toward the east, giving place to marine shales. Coal seams are confined to the areas of sandstone and shale, there being none in the fine-grained marine shales, which extend from the longitude of central Colorado to the eastern border of the Cretaceous, except in the sandy strip along the southern border in New Mexico. In the sandstone wedges, land and marine conditions alternated, the former continuing for long periods at many localities, long enough to permit accumulation of thick coal seams. At the same time, the distribution of coal is indefinite. In the southern basin within New Mexico, the coal seams are important locally, but they are irregular and there are broad spaces, which are altogether barren. The story is similar in the Uinta Basin; coal seams are very numerous in the Mesaverde, but they are not persistent; portions of the column showing workable seams in one district are apparently without trace of coal in others. The features are the same in the Green River Basin; an extensive coal field in Sweetwater County of Wyoming has many lenses yielding coal of excellent quality, but at the same horizons in other counties there is either no coal or the seams are mere streaks. Farther east, the sandstones thin away and all traces of coal disappear. Elsewhere in Wyoming the distribution of coal is certainly capricious; here and there one finds a seam thick enough to be digged for local supply, but such exposures are separated by intervals of many miles. In Montana, coal occurs only in scattered spots, while the intervening spaces seem to be barren. Seams of workable coal are more numerous in Alberta and the lenses are larger; conditions favorable to coal accumulation existed in a large area. But there, as in the United States, the sandy coal-bearing formation thinned away toward the east and was replaced with shale, in which no coal is known.

The sandy deposits, containing Benton coals, reach only to the 109th meridian, aside from an isolated deposit in Colorado near the 108th. The most westerly localities at which coal has been found are in southwestern Utah, where the conditions are not in accord with the assertion that coal is present only in association with prevailingly coarse materials. In those fragmentary fields, the rocks

are, in very large part, clays, clay shales and limestones, the last serving occasionally as roof or floor to coal seams. The area must have embraced not less than 2,000 square miles and its surface must have been a broad mud flat during formation of the coal seams. It was little above the sea-level. At 50 miles farther east, the conditions are wholly different, for there the coals are associated with sandy deposits, as they are farther north. The relations appear to give support to Gilbert's suggestion, offered more than 40 years ago, that the Wasatch Mountains were the source whence the sediments were derived. In that case, the conditions would be normal, for the sluggish streams, carrying only fine materials, would build up merely a mud flood plain, such as one sees at localities along the Atlantic coast, on which peat deposits are accumulating. The deposits are largely sandstone in northeastern Arizona, where they contain 3 coal seams near the base. Benton rocks in the southern part of the San Juan Basin have about 66 per cent. of sandstone and have 3 coal seams; but the sandstone decreases northwardly and the coal disappears. The condition is similar in the northern or main portion of the basin.

The Ferron sandstone of Castle Valley, Utah, at eastern base of the Wasatch Mountains, contains many and irregular coal seams, of which some are locally important; but these are confined to the southern part of the valley, where the sandstone is several hundred feet thick; no trace of them remains in the northern portion, where the sandstone has become thin. The Frontier sandstone contains several seams, yielding excellent coal, in Uinta County of Wyoming, but farther east the sandstone becomes thin and the coal disappears. The Bear River formation, of fresh-water origin, has numerous coal seams but it thins away rapidly toward the east.

The Kootenai has no coal in the southern portions, the first appearance being in the Black Hills region of northeastern Wyoming; there and in the Bighorn Basin of the same state the rocks are chiefly sandstone and contain patches of coal, which are sources for local supply; but they are far apart in Wyoming as well as in Montana, there being coal in only an insignificant part of the exposed area. In Alberta and the adjacent portion of British Columbia, the individual seams cover greater areas than in any part of the

United States and the quantity of coal in some fields is enormous, there being 198 feet in the Alberta section of the Crowsnest field. But the formation thins eastwardly and it has not been recognized in Manitoba.

The distribution of coal in the several formations of the Cretaceous is wholly similar to that of peat deposits on coastal plains.

2. *Structure and Other Characteristics of the Accompanying Rocks.*—Information respecting these topics is lacking for many districts but details given by observers in many others are all in accord and are sufficient.

The Wealden sandstones of England contain driftwood and often have rippled surfaces; the shales have sun cracks, while limestone slabs, in many cases, are rippled and are marked by trails. Stems of trees, replaced with silica or oxide of iron, abound in the rocks between coal seams. Grains of coal are in Wealden sandstones of Westphalia. The Upper Cretaceous of Borneo and Queensland has grains of coal in the sandstones. In Queensland, sun cracks, worm burrows and trails are notable features of the sandstones, which are cross-bedded at many places. Fragments of tree stems, usually silicified, characterize the sandstones of Queensland, New Zealand and Greenland.

Many observers report that the Laramie deposits in Colorado and Wyoming are extremely irregular, sandstones and shales being lenses. In Montana, the sandstones assigned to this formation are often cross-bedded, rippled and contain fossil wood. The Fox Hills sandstones are much cross-bedded in parts of Colorado and Montana. Fossil wood is reported from one locality in southern Colorado, where cross-bedding is not uncommon.

The Pierre sandstones show cross-bedded layers in the Cerillos field, where some of the beds are locally conglomeratic. Cross-bedded and rippled sandstones are in the southwestern part of the San Juan Basin, and petrified stumps and logs abound at at least one locality on the eastern border of the basin. In the Grand Mesa portion of the Uinta Basin, the sandstones and shales are so irregular in distribution that many times sections, separated by only a short interval, are unlike; cross-bedding in sandstones was observed frequently. Within Montana, the sandstones of Electric and Liv-

ingston fields are much cross-bedded, while in Cleveland and Big Sandy fields, rippled surfaces were observed and the shales and sandstones are in rude lenses. So also in the Milk River field where all deposits are lens-like and the sandstones are cross-bedded. In Teton County, the Two-Medicine formation is characterized by great irregularity of the deposits and fossil wood abounds; the Virgelle (Lower Eagle) sandstone is coarse and cross-bedded. The conditions in Alberta are similar; the Belly River sandstones have been described as cross-bedded, rippled and marked by trails; the same features were observed farther north on Pine River.

The Benton in New Mexico, has, near the base, the Tres Hermanos sandstone, cross-bedded, rippled and locally conglomeratic, which persists to the northeastern corner of the San Juan Basin. Similar features are recorded in the southwestern part of that basin as well as from localities in the Uinta Basin. The Dakota is usually more or less cross-bedded and holds local conglomerates. The Kootenai of New Mexico is cross-bedded and locally conglomeratic; it is rippled, cross-bedded, locally conglomeratic in the Black Hills, where petrified wood, chiefly cycads, is abundant. The conditions are similar in Montana, while in Alberta the same features were observed at many localities.

These features, characterizing the rocks of the several formations, indicate deposition in, at most, shallow water, as well as subsequent exposure to subaërial conditions. The rippling and cross-bedding were due to water movements in probably most cases, but it is possible that there has been too great readiness to accept this mode of origin as almost universally applicable. The writer has observed the ripple marks in rocks of several formations and has compared them with wind ripples seen by him in the sandy areas in the western states and in Russia and Prussia, as well as on broad river benches. The resemblance to fossil ripples, seen in many beds, is so great that the mode of origin must be the same for both. It may be also that some of the "cross-bedding" was due to wind action. The complex structure shown in many diagrams is precisely that of the æolian limestone of Bermuda and observable more or less distinctly in many dunes; the "current bedding" is clearly due to stream action. The presence of tree stumps and logs is evidence

of shallow water and suggests the action of floods, which dropped their load on the broad surface, which was exposed during the intervals between floods.

3. *The Form of Coal Deposits.*—Cretaceous coal seams are lenses. No statement to this effect occurs in any of the older works, as nearly all students, prior to less than 25 years ago, held in a somewhat hazy way, that coal seams are continuous deposits. Comparison of sections in all fields proves that this conception was erroneous. The Wealden coals of Hannover are local, present in one section, absent in others, and in all cases they have small areal extent. There is a rather persistent coal horizon at the base, which seems to be made up of overlapping lenses. The Lower Quader has only nests of coal, which occasionally become workable; the Hungarian coals are well-defined lenses as are those of Queensland; and the detailed studies in New Zealand have proved lens form in the great seams.

The condition in North America is so marked that it has been noted by the great majority of observers during later years. Occasionally, a seam has an area so extensive that the describer is unwilling to commit himself as to the form. But it must be remembered that, even though the lenses have an area of hundreds or thousands of square miles, the general features are the same with those of smaller lenses, united by transgression to form the large one.

The Laramie coals are in lenses, usually small and thin within the United States; the great bed of the Saskatchewan in Alberta becomes only a thin deposit of carbonaceous shale in its southern extension. The Fox Hills seams are lenses, usually thin or impure, but locally important and workable in considerable areas. This feature is noteworthy in all districts along the eastern base of the Front Ranges in New Mexico, as well as the southern tier of counties of Wyoming. The Middle Pierre (Mesaverde) is probably the most productive formation with usually one or more workable seams; but its seams are like those of the newer formations. They are variable and uncertain in New Mexico; in the Uinta Basin, west from Grand River, portions of the section, containing workable coals in one district, are wholly barren in others; east from that river the coals are local, important here, unimportant or absent else-

where; the Mesaverde coals of Green River Basin attain commercial importance in only one county; in Montana the lenses are usually small and thin; in Alberta, the coals are present in a great area, and often workable, but available details merely suggest, they do not prove that the seams are lenses.

Benton coals are present in only a small part of the Cretaceous area, but, wherever they have been studied, the lens form is characteristic. In southwestern Utah, in Castle Valley of that state, in Gunnison Valley of Colorado and in Uinta County of Wyoming, they are distinctly lenticular. The Dakota coals are merely insignificant lenses. The Kootenai is without coal south from northern Wyoming. There, within the Black Hills districts, coal lenses of typical form are present but they are all small, nowhere embracing more than a score of square miles. An occasional lens has been found in the Bighorn Basin. The lenses are few and unimportant in southwestern Montana; they become numerous and some attain workable thickness in Lewistown and Great Falls fields; but in Teton County, on the northern border, there are only insignificant nests. In Alberta, on the contrary, as well as in the adjacent part of British Columbia, the seams are numerous and the quantity of coal is enormous. Comparison of sections leaves no room for doubt respecting the lenticular form of the seams.

The lenses ordinarily show increase of foreign matters toward the borders, the coal is broken by fine partings and very often it becomes at last merely carbonaceous shale with laminæ of coal. Sometimes the lenses are connected by a stretch of black shale, but commonly no such bond exists and a barren space intervenes. These lenses, great and small, are similar to peat deposits on broad river plains and even more strikingly to those on coastal plains; at times, these are separated by broad spaces, forested; at others they are united by carbonaceous muds, while at still others, the peat of several lenses has become continuous by transgression.

4. *Contemporaneous Erosion.*—The effects of contemporaneous erosion are conspicuous. The curious intermingling of coal and débris, observed at one locality in the Loewenberg area of Silesia, seems to be explicable only by the supposition that it represents a washed out swamp. The presence of coal grains in sandstone may

signify that a coal seam in process of formation was exposed. Local conglomerates in many sandstones occupy the channelways of rapid streams; local unconformities between sandstone and shale suggest changes in direction of drainage. The coal seams themselves appear to have been subjected to subaërial erosion and to have been traversed by streams as in modern swamps. "Horsebacks" or "rolls" of the roof have been found wherever extensive mining operations have been carried on. They mark channel ways of varying width and depth, now filled with material like that of an overlying deposit; sometimes the material is the same with that forming the immediate roof, in which case the stream was probably contemporaneous with the bog; but not infrequently the channelway was excavated after the roof had been deposited. The conditions are commonplaces in modern deposits.

5. *Soils of Vegetation.*—Reports on areas of Cretaceous coal in North America give few instances where soils of vegetation have been observed in the rocks between coal seams. One must not forget, in this connection, that, generally speaking, observers have been compelled to depend on natural exposures, which are imperfect, and that the work has been done at cost of much personal discomfort. But the few illustrations available show that the condition is less rare than the record shows. A dense growth of *Sphenopteris,* in place, has been reported from the Wealden of England and a similar growth of *Equisetum* from that of Hannover. A grove of large trees exists in the Upper Cretaceous of Queensland, clearly in place of growth, where they were buried by drifting sand; an ancient soil in New Zealand contains roots in place. The Upper Cretaceous of Greenland has bands with ferns, conifers, dicotyledons, erect stumps and silicified wood. An old soil was seen on Pine River of Alberta in the Lower Kootenai, which contains erect stems, evidently in the place of growth.

6. *The Roof of Coal Beds.*—Coal seams may have shale, clay, sandstone or limestone as the roof. In parts of some mines one finds shale as roof in one part, but sandstone in others; the variation being due, apparently, to local removal of the shale during or prior to deposition of the sandstone. It may be marine limestone or a detrital deposit containing marine fossils. Occasionally, a parting

of marine limestone serves as roof to one bench and as floor to the other. These limestones are thin but they are proof of submergence, due perhaps to change in course of drainage or to the breaking away of a barrier, which protected the swamp from sea-invasion, a by no means rare phenomenon on the New England coast. The roof is apt to be irregular.

7. *The Coal Seams.*—Where succession is undisturbed and deposition appears to have been continuous, the roof material ordinarily becomes more and more carbonaceous at the base and passes gradually into bone or into impure coal, with normal structure, a faux-toit. But the transition is abrupt in many cases where no evidence of disturbance by erosion is apparent; a condition which leads to the suggestion that a suddenly increased influx of mud or fine sand ended the bog's existence. In such cases the contact between coal and roof is irregular, defining the bog surface.

Accumulation of vegetable material was rarely continuous during long periods, though there are seams several feet thick, which are said to be unbroken by partings of any sort. Commonly, however, coal seams are divided into benches by partings of mineral charcoal, clay, sand or limestone, which indicate longer or shorter periods of interruption. In many cases, this interruption was not complete and the parting consists of bone or bony coal, at times closely resembling cannel; but when the parting consists of inorganic matter, it is proof of at least local cessation. The thickness of partings usually varies within narrow limits, but in some cases it is so great as to attract the attention of even a casual observer. Cžjžek notes the thinning away of a considerable interval and the consequent union of two important seams, with increased thickness of coal. In the Denver Basin, one parting increases from a mere film to 25 feet within a few miles; the partings in the Carbonero seam of the San Juan Basin thicken in one direction, so that the great bed, 100 feet thick, becomes three, with thicknesses of 7, 30 and 15 feet respectively, in a vertical space of 200 feet. Taff describes a parting, which increases from zero to 16 feet within 2,000 feet, the exposures being complete in one mine. The Trinidad seam, 11 feet thick near Trinidad, Colorado, becomes 58 feet within 3 miles by thickening of the partings. Lee has given details making almost certain that

7 coal seams, wholly distinct and separated by thick intervals, unite within 4 miles into one, 42 feet thick. Partings contain fossils; in southwestern Utah, Lee saw a limestone parting with brackish-water forms; at another locality a seam with marine limestone as roof and floor has a parting with fresh-water fossils. Clay partings frequently have remains of plants.

Benches of coal beds seams often differ so much as to make certain that conditions were not the same during the several periods of accumulation. One bench may yield caking, and another may consist of non-caking coal; in one, the ash may be unimportant while another may be so dirty as to be worthless; one may thin away to disappearance while others overlap it. Details respecting the benches are given only for districts where mining operations are on large scale, but enough is known to justify the old method of regarding benches as separate coal seams.

In a general way, Cretaceous coals vary from massive to laminated, the latter with alternating bright and dull laminæ—and these types are found throughout the whole section. Ordinarily, woody structure is not apparent to the naked eye, but it is distinct in many places. The Upper Cretaceous coal of Silesia is xyloid; a seam of Moorkohle is near Mährens-Trubau; the coal of the Boulder District is almost as xyloid as the Eocene coals of the Dakotas; it contains logs, carbonized, jetified or silicified. Most of the Wealden coal in Hannover is black and apparently without woody structure, but in the same section with the black coal one finds lignitic brown coal and even Blätterkohle, the latter being an accumulation of leaves and not related to the Blätterkohle of the lower Rhine region.

Few notes are available respecting microscopic structure of Cretaceous coals. v. Gümbel[145] studied only jet from Raschwitz in Silesia and coal from the Wealden of Hannover. Woody structure is well-preserved in the former; the latter contains numerous remains of leaves with clumps of wood cells and bark parenchyma, all easily recognized. Thiessen[146] examined coal from the Denver Basin, probably Fox Hills. So close is the resemblance to that

[145] C. W. v. Gümbel, *Sitzb. bay. Akad. Wiss.*, 1883, Math.-Phys. Kl. I., pp. 157, 160.

[146] R. Thiessen, "The Origin of Coal," pp. 241–245.

from the Eocene of Montana and Dakota that he believes the general conditions during accumulation were similar. Woody parts are more compressed in the older coal, but the canals of wood fibers are well shown and appear to be filled with resin. Resins form a large part of the mass, while spores and pollen exines compose not more than 5 to 10 per cent.; the "fundamental matrix" or binding material is derived, as in lignite, from cellulosic substances; all gradations are present from fibers to a homogeneous mass. The fibers are mostly xylum elements of plants, but whether of trees, shrubs or herbs is not always determinable.

8. *The Floor of Coal Seams.*—The floor may be clay, sandy or clayey shale, sandstone or limestone. Occasionally the transition from coal to floor seems to be abrupt, but in most cases there is a faux-mur. Even where this seems to be wanting, the basal part of the coal is, in most cases, higher in ash than that above; frequently the faux-mur is bone and occasionally it resembles the "coarse coal" of the Carboniferous. Limestone floors have been reported only from southwestern Utah, where they contain marine fossils. Bulging floors have been reported from many localities. They are due in some instances to irregularity of the surface on which the coal accumulated; in the Boulder District, petty swales were numerous, in which accumulation began and afterward crossed the low divides—after the manner so familiar in recent peat deposits. But "rolls" in the floor often mark the courses of streams crossing the swamp in its earlier stages.

American reports contain few references to the presence of roots in the floor; two notes have been given for the Trinidad-Raton area and D. White recognized characteristic underclays with roots in the Boulder District. But the scantiness of references in detailed reports indicates merely that the reporter did not look for the roots; Lesquereux,[147] long ago, asserted that most of the underclays are full of roots or rootlets. He visited exposures in the Raton Mountains, Canyon City, Golden, Marshall in Colorado and Black Buttes in Wyoming; at most localities, he found the shale containing such abundance of roots that these seemed to be a compact mass.

[147] L. Lesquereux, "On Formation of the Lignite Beds of the Rocky Mountains," *Amer. Journ. Sci.*, Vol. VII., 1874, p. 30.

The presence of roots in the floor is apparently the ordinary condition in much of Europe. Rzehak[148] says that the Wealden coals of Hannover are distinctly autochthonous, there being rootstocks in most of the underclays. Grand' Eury[149] states that he had found roots in the floor of Cretaceous coal at many places. At la Liguisse and les Gardies in the Causses there are many roots in place under the seam mined there. The Middle Cretaceous at St. Paulet shows roots in the marly mur of some coal seams; these he says are in place for some of them cross leaves of dicotyledons lying flat in the rock. In his later paper, he reports that, at Sarladais, roots in thé mur give rise to stems. Similar conditions were seen in the Upper Cretaceous at Valdonne.

9. *The Fauna.*—Fresh-water forms predominate in the Laramie, the Judith River, the Bear River and occur occasionally in other formations; but for the most part the Cretaceous fauna is marine. Discussion of the faunas as such has no place here, but reference to some features is necessary.

The Lower Colorado fauna is characteristic throughout the whole region from western Utah to the eastern border; it is present in the limestone roof and floor of coal seams as well as in the occompanying shales and in the coal-bearing sandstones of Utah. The Pierre fauna abounds in the fine shales and occasional limestones, but it abounds equally in the Middle Pierre (Mesaverde) sandstones of New Mexico, where it is found in profusion at several horizons. The fauna is practically the same, be the rock sandstone or shale. The depth of water in western Utah was not great, for coal beds are numerous, one of them having a parting with fresh-water mollusks, though the roof and floor are marine limestone. The character of the rock and the numerous coal seams make the condition equally clear for the Mesaverde of New Mexico. The marine faunas give no support to the opinion that deep-sea conditions existed anywhere, but they make probable that the body of water, covering at times the greatest part of the Cretaceous area, was a very shallow sea. Fineness of sediments, in general, may be taken as indicating distance from the source of supply.

[148] A. Rzehak, *Zeitsch. f. pr. Geologie*, Vol. XXII., 1914, p. 8.

[149] C. Grand' Eury, Autun, 1902, p. 127; *C. R.*, t. CXXXVIII., 1904, 669, 741.

10. *The Flora.*—The Cretaceous coals are usually so far advanced in conversion as to give little information respecting the plants by which they were formed. Knowledge of the flora of the period is derived from fragmentary material found in the rocks; that has been transported, it represents mostly the upland vegetation and tells nothing about the swamp plants. In the United States and Canada, the coals are often rich in resins, indicating that conifers entered largely into their composition; such wood as has been recognized seems to confirm this conclusion. Cycads were abundant locally during the Kootenai but conifers and dicotyledons were predominant during the Upper Cretaceous, when ferns and lycopods appear to have been subordinate. Memoirs on European coals, consulted by the writer, usually contain little information upon the subject. Wood, fully recognizable, is present in the Upper Cretaceous coal of the Loewenberg region, but in the Grünbach coal, no structure is shown, though the stems and branches retain their form. The Wealden of Hannover contains abundance of conifers, cycads, lycopods and ferns; the plant remains in coal must be distinct there. Dunker thinks that the "black coal" of that region was derived from lycopods and ferns, because they are the only forms found in it; the lignitic brown coal is largely of conifer origin, as the stems occurring in it resemble *Pinus*.

11. *Chemical Relations.*—Discussion of the chemical relations of Cretaceous coals must be deferred until the older coals have been studied; but it may be well to call attention to some matters.

Like the Tertiary coals and some peats, these coals are resinous in many districts. Cannel is present at several horizons, with all features which mark the sapropels or Lebertorfs of later times. The carbon content is higher than that of Tertiary coals, but progressive enrichment with increasing age is less marked. In the Fox Hills the extremes of carbon are 73 and 84; in the Pierre, 71 and 84; in the Benton, 77 and 83, and in the Kootenai, 75 and 85. No note has been taken here of metamorphosed coals; anthracite is present at several horizons. No ultimate analyses of the Laramie coal are available and there are very few of the Kootenai. The variations are small compared with those in the Tertiary. In the Cretaceous as in the Tertiary, not all accumulations of vegetable materials had

attained the same degree of enrichment before burial; the minimum of the Pierre rarely falls below 75, but there are seams with only 71 or 72. The condition is well marked in Hannover, where the "black coal" has 89 per cent. of carbon, the brown coal, 73, while the Blätterkohle is almost unchanged—the several types occurring in the same vertical section.

INTERRELATIONS OF THE FOSSIL FUELS.*

III.

By JOHN J. STEVENSON.

(*Read November 2, 1917.*)

THE JURASSIC AND TRIASSIC COALS.

The Jurassic.

Like the Cretaceous, this is barren in the greater part of its extent within Europe and the productive areas are of limited extent, though some of them are important. Conditions favoring accumulation of coal existed in widely separated localities elsewhere, as in Siberia, Australia, New Zealand and Alaska; in some of which the deposits may prove to be valuable. The geologic features have material bearing upon the problem under consideration in this study.

Great Britain.—British geologists have grouped the Jurassic deposits into Upper, Middle, Lower Oölite and the Lias. Transition from the Cretaceous is often gradual. Local deposits of coal are in the Lower Oölite and soils of vegetation have been observed in both the Upper and the Lower Oölite.

The Purbeck "Dirt Beds," soils of vegetation near top of the Upper Oölite, have been mentioned in most of the text-books on

* Part I. appeared in these *Proceedings,* Vol. LV., pp. 21–203; Part II., in Vol. LVI., pp. 53–151.

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geology. They were described first by Webster, then by Buckland and de la Beche and still later by Mantell.[1] The chief "Dirt Bed" with erect stumps was recognized by all as a black loam with remains of tropical plants, which accumulated where they grew. This soil, about one foot thick, contains slightly rounded fragments of stone and, as Webster showed, is the original matrix of the silicified stems; for, wherever exposed, it contains trunks of coniferous trees. partly in the black earth and partly surrounded by the overlying calcareo-silicious strata. The intervals are very nearly the same as those seen in recent forests and the erect stumps or stools of the large trees with attached roots are in their original soil. Associated with the coniferous stems are others of cycad-like plants, also silicified. The same condition was observed at another locality, where the dip is 45 degrees and the stems are vertical to the plane of bedding.

Mantell states that the "Dirt Bed" has a considerable quantity of lignite and of waterworn pebbles. While the prevailing trees are conifers, there is abundance of plants allied to *Zamia* and *Cycas*. Many of the trees are erect, as if petrified during growth. The roots are in the black clay, and the stems reach into the overlying calcareous rocks. Just prior to Mantell's visit, a large area of the "Dirt Bed" has been exposed preparatory to removal that the underlying rock might be quarried. Some of the trunks were surrounded by calcareous earth; the upright stems were only a few feet apart and usually were not more than 3 or 4 feet high; without exception they are splintered at the top as though they had been wrenched or snapped off. All are without bark and have a weather-worn surface, resembling that of posts set between tides. Two other dirt beds were examined by Mantell, who obtained cycads from both: the principal bed is so little consolidated that he was able to dig out several cycads and to prove that they are actually *in situ*.

[1] T. Webster, "Observations on the Purbeck and Portland Beds," *Trans. Geol. Soc.*, II., Vol. 2, 1829, pp. 41, 42; W. Buckland and H. T. de la Beche, "On the Geology of the Neighborhood of Weymouth, etc.," the same, Vol. 4, 1836, pp. 13–15; G. A. Mantell, "Geological Excursions around the Isle of Wight," 3d ed., 1854, pp. 286–290.

The conditions described by Mantell recall those seen by Russell[2] on the Yahtse of Alaska. That stream, issuing as a swift current from beneath a glacier, invaded a forest area and surrounded the trees with sand and gravel. Some stems, still retaining their branches, projected above the mass but most of the decaying trunks had been broken off by the wind and entombed in prostrate position. The phenomenon is familiar to all who have travelled along rivers with broad bottoms. Lyell states that the top beds of the Portlandian or middle division of the Upper Oölite, containing marine shells, were covered with fluviatile muds on which *Zamia* and cycads grew.[3] He remarks that each dirt bed may represent a notable period of time; 2 to 3 feet of vegetable soil is the only product of very old tropical forests.

The Kimmeridge Clay, at base of the Upper Oölite, contains, according to Phillips,[4] a highly bituminous shale, which is utilized as fuel at Kimmeridge on the Purbeck coast. As shown in cliffs near that place, the clay, finely laminated and grayish-yellow, with remains of plants and animals, passes gradually into a bituminous shale, which is dark brown, lusterless, slightly calcareous and burns with a smoky flame. Lyell[5] states that this sometimes becomes an impure coal and that in Wiltshire it resembles peat. Plant remains are rare and the bitumen may be due, at least in part, to animal matter.

The coal at Brora in Scotland belongs to the Great Oölite or highest division of the Lower Oölite, which in that region is a mass of sandstones and shales. The seams at Brora are thin, but one of them was worked many years ago for local use. This petty area was described by Murchison, whose measurements are (1) fossil shells, marine, quartz grains, carbonaceous matter, all cemented by calcareous material, passing downward into a mass of compressed leaves and stems, in turn becoming shaly coal, 2 feet, 7 inches; (2) coal resembling jet, divided midway by a parting of pyritous, in-

[2] I. C. Russell, "Second Expedition to Mount St. Elias," 13th Ann. Rep. U. S. Geol. Survey, 1893, Part I., p. 14, Pl. XII.

[3] C. Lyell, "Elements of Geology," 6th ed., New York, 1866, pp. 391–393.

[4] J. Phillips, "Outlines of Geology of England and Wales," Part I., 1822, pp. 127, 128.

[5] C. Lyell, "Elements," p. 394.

durated clay; in burning it gives off the characteristic odor of imperfect coal; the powder is brown, 3 feet, 3 inches to 3 feet, 6 inches. This is one of the few localities in Britain where coal is present in workable thickness, but the coal is inferior and no longer of even local importance. Miller[6] has given some notes concerning the Oölite conglomerate of Eigg, one of the Hebrides. The Scuir of Eigg is described as a mass of igneous rock resting on a pile foundation, composed of pine stems, laid crosswise. These stems of *Pinites eiggensis* are transported material; they are so numerous near Helmsdale that the people collect them and burn them into lime. The tree was as abundant on the mainland of Scotland as the Scotch fir is at present. It was of slow growth but attained gigantic size. Witham's study of the structure proved it very different from that of the Carboniferous conifers. The wood abounds in turpentine vessels or lacunæ of varying size, which are well defined, the minutest detail of structure being distinct. Occasionally Miller found a thin streak of brilliant lignite, resembling that of Brora, but in every case it was only the bark of a tree.

The Lower Oölite in Lincolnshire, according to Morris,[7] has soils of vegetation with well-defined underclays. In one section, bituminous clay, 18 inches thick, rests on "gray clay with vertical stems and roots descending from the overlying bed." Another section shows the bituminous band only 6 inches thick with 7 feet of underclays containing vertical stems. At Dane's Hill the root-bed is only 9 inches, but at Aunby Cutting, he saw two bituminous clays, of which the upper contains lignite and impure coal. Each has its root-bed below.

The Inferior Oölite, at base of the Lower Oölite, has some coal in Yorkshire. Phillips[8] recognized two groups of sandstones and shales along the coast. The lower consists of white to yellow sandstones and shales, with irregular seams of bad coal; the plants are cycads and ferns but equisetiform remains are in the upper layers, standing vertically as if in place of growth. A thin irregular seam

[6] H. Miller, "The Cruise of the *Betsy*," Boston, 1862, pp. 51–55, 71.

[7] J. Morris, "On Some Sections in the Oölitic District of Lincolnshire," *Quart. Jour. Geol. Soc.*, Vol. 9, 1853, pp. 326–331.

[8] J. Phillips, "Geology of Yorkshire," 2d ed., London, 1835, Part I., pp. 8–10, 65, 66, 173, 174.

of coal near the top has been mined at some places. The higher group contains thin irregular coal seams; one, 8 inches thick, rests on 4 feet of grit holding carbonaceous markings and at 80 feet lower a white sandstone, associated with coal, has similar "coal pipes." Coal seams are present throughout northeastern Yorkshire and occasionally become thick enough for mining, but the coal is not good. The flora consists preëminently of ferns, but cycads and conifers are abundant.

Fox-Strangways and Barrow[9] have given additional details respecting the east coast of Yorkshire. A section on Gresthope Bay, where the Middle Estuarine Series of the Lower Oölite consists of thin-bedded sandstones and shales, shows (1) black coaly shale, 0 feet, 3 inches; (2) soft, white sandstone with rootlets, 1 foot; (3) gray shale, 5 feet; (4) sandstone and shale, 3 feet, 6 inches; (5) black shale, 1 foot, 6 inches; (6) fine laminated sandstone, 1 foot, 6 inches; (7) fine laminated shale, 6 feet; (8) false-bedded sandstone, with irregular patches of coal, plants, pyrite and carbonized wood, 21 feet. The last rests on the Millepore Series, in which rippled sandy shales occur; the impure coal at top of the section rests on the sandy floor into which the plants thrust their roots.

The Lower Estuarine series is exposed at many places between Whitby and Scarborough, where it underlies the Millepore Series. A section at Blea Wyke shows a thin coal seam roofed by 30 feet of dark shale and resting on 2 feet of underclay, below which is ferruginous sandstone, 12 feet, containing great numbers of erect stems, allied to *Equisetites* and often 5 feet high. Two other seams, 2 and 3 inches thick and separated by 2 feet of soft sandstone, are at 18 feet below the top seam. The lower one rests on 6 feet of dark shale overlying 24 feet of false-bedded sandstone. In the Hawsker District, a coal seam, 4 inches, is at only 3 feet above the Dogger and the intervening shale contains roots. The Dogger in this district has vertical stems of *Equisetites*. The Middle Estua-

[9] C. Fox-Strangways, "The Geology of the Oölitic and Cretaceous Rocks South of Scarborough," Mem. Geol. Surv., 1880, p. 5; "The Geology of the Oölitic and Liassic Rocks to the North and West of Malton," Memoirs, 1881, p. 8; the same and G. Barrow, "The Geology of the Country between Whitby and Scarborough," 1882, pp. 31, 32.

rine Shale Series at Cloughton Wyke has vertical *Equisetites* in sandy shale and, at base, a false-bedded sandstone as in the area south from Scarborough.

Judd[10] has given the section of a pit at Ufford, Northampton, in the Lower Estuarine sands, which shows a thin seam of lignite, below which are 3 feet of purplish clay and 3 feet of sand, both of which contain plant remains in vertical position; he considers that the manner of occurrence indicates that the plants are *in situ,* and that they were embedded by quiet deposition as they stood. Kendall[11] states as result of study of clays along the Yorkshire coast, that every coal seam examined by him rests on a root bed.

The resemblance of the Estuarine Series to the Carboniferous Coal Measures has been emphasized by several observers; the resemblance to those of the Cretaceous is equally marked. The deposits were laid down in shallow water at many horizons within the Oölite. Ramsay[12] and his associates observed that, in their district, there is much false-bedding in both the Great and the Inferior Oölite as well as in the Forest Marble, which has many fragmentary fossils in its sandy layers. Even the deposits containing marine forms frequently give evidence of deposition in shallow water. Scrope[13] reported that many layers of the Forest Marble Beds (Great Oölite) in the neighborhood of Bath are rippled and that they show impressed footprints of various types. Those layers contain rolled fragments of shells, corals, echini, etc., and exhibit the characteristic features of a shore deposit. According to Lyell, rippled bands of Oölite are known in broad areas and are utilized for roofing.

The Lias of England is without coal, though at some localities jetified wood is abundant. The soils of vegetation in Yorkshire were described by Conybeare and Phillips:[14] Conybeare stated that

[10] J. W. Judd, "The Geology of Rutland," Mem. Geol. Survey, 1875, pp. 104, 105.

[11] P. F. Kendall, in letter of May 27, 1917.

[12] A. C. Ramsay, W. T. Aveline, E. Hull, "Geology of Parts of Wiltshire and Gloucestershire," Mem. Geol. Survey, 1858, pp. 10, 12, 14.

[13] G. P. Scrope, "On the Rippled Markings of the Forest Marble Beds," *Proc. Geol. Soc.,* Vol. 1, 1834, p. 317.

[14] W. D. Conybeare, "Outlines of the Geology of England and Wales," 1822, p. 272; J. Phillips, "Geology of Yorkshire," 1835, p. 66.

gigantic reeds are in the cliffs near High Whitby. They appear to have been rooted in a bed of shale or slate-clay and their remains protrude into a sandstone, 5 feet thick. Those which are erect retain their shape, but prostrate stems are compressed. The tops seem to have been broken off and the woody matter has disappeared, there being only sandstone casts. Phillips gave more of detail. He reports that a Lias sandstone near Whitby contains great numbers of cylindrical plants like Equiseta, which are erect. They were broken off above and in some cases do not reach to the top of the bed. They are broken off below but commonly pass to the lower surface of the bed and, at times, the lower joints reach into the underlying shale. The conditions have led some to regard these plants as *in situ,* but Phillips prefers to believe that they were floated down and that they were kept vertical by the weight of their roots. The writer is compelled to dissent from this explanation. If the trees had been floated down stream, they would not remain vertical, even though it be conceded that the weight of their roots would keep them vertical while floating. As soon as the roots had touched bottom, the current, gentle or strong, would push the stem down stream. "Snags," only too familiar in our western rivers, invariably point down stream. Grand' Eury was able to determine the direction of currents in St. Etienne coal basin by means of "snags" enclosed in the sandstones. Murchison,[15] in a brief note referring to the observations by Phillips, stated that he had discovered another locality at the same horizon, but 40 miles away and well inland. At both localities, the stems of *Equisetum columnare* are in the normal position and appear to be rooted in the black shale. The only fossil accompanying these plants is a freshwater bivalve.

France.—The Jurassic deposits of France contain some thin seams of coal, which rarely have more than local importance. de Serres[16] reported upon the coals of Aveyron, belonging to the Lower Oölite. The mines are on the plateau of Larzac within an area of

[15] R. I. Murchison, "On the Occurrence of Stems of Fossil Plants in Vertical Position, etc.," *Proc. Geol. Soc.*, Vol. 1, 1834, p. 391.

[16] M. de Serres, "Des houilles séches ou stipites des terrains jurassiques, etc.," *Bull. Soc. Geol. France,* t. 16, 1859, pp. 97–99, 104, 105.

not more than 60 by 200 kilometers. The only workable seam is extremely variable. The greatest thickness is in the group of mines known as Nuejols, where the seam is 70 to 80 centimeters. The center of the area is on the summit of the plateau, where, in two mines, the thickness is but 45 centimeters. The decrease continues toward the north, there being only 12 to 15 centimeters at 10 kilometers north from La Cavalerie. The lower part of the coal group is largely calcareous and the limestones have both marine and freshwater forms. The coal rests directly on black shale; the roof is similar but more carbonaceous and, at times, has a wood-like structure; it is at most 12 centimeters thick and is combustible. The coal yields a very fair coke with imperfect metallic luster. The lenticular form of the seam is distinct, for the thickness decreases in all directions from La Cavalerie.

Austria.—The Jurassic coals of Upper Austria belong to the Grestener beds at the base of the Lias. They have been described by Lipold[17] and his associates. Hertle, in his notes upon the mining area of Bernreuth on the eastern side of this region, states that Cžjžek's profile shows a marine limestone between two coal seams, which contains *Mytilus, Pleuromya* and *Pecten,* and a sandy shale in the same section has *Ammonites.* Sphærosiderite concretions as large as half a cubic foot are fossiliferous. These calcareous deposits were not exposed at the time when Hertle made his examination, but he saw a sandy shale with *Pholadomya* and *Mytilus.* The coal seam, which is mined, is 3 feet thick and rests on an underclay containing remains of plants. The coal looks like good coal but it has 42 per cent. of ash.

Near Gresten, according to Rachoy, the coal seams are in a sandstone group. One tunnel cut seven streaks of coal, one to 12 inches thick, while a shaft passed through 16 seams, 3 inches to 3 feet thick. The roof and floor are sometimes clay and sometimes sandstone. The thickest bed yielded a good caking coal with less than 4 per cent. of ash; the dip is about 20 degrees. Plant remains are poorly preserved but marine fossils occur in fine condition. At

[17] M. V. Lipold, G. v. Sternbach, J. Rachoy and L. Hertle, "Das Kohlengebiet in den nordlichen Alpen," *Jahrb. k. k. Geol. Reichsant.,* Band 15, 1865, pp. 29–61.

Hinterholz, Rachoy found dips of 40 to 60 degrees and one seam, 4 feet 6 inches thick, was mined. The coal yielded 66.3 per cent. of high-grade coke, used in iron-making.

v. Sternbach's section near Grossau is (1) shale, 6 inches; (2) coal and shale, 1 foot; (3) clay shale, 1 foot; (4) coal, 3 feet; (5) shale, 6 inches; (6) sandstone, 6 feet; (7) carbonaceous shale, 6 inches; (8) coal, 6 inches; (9) carbonaceous shale, 6 inches; (10) sandstone, 1 foot; (11) shale, not measured. This, like many others, closely resembles typical short sections in Cretaceous and Carboniferous coal measures. The workable seam, Number 4, has lenses of shale, so that not more than three fourths of the output is clean coal. The roof is black shale but the floor is fine to coarse sandstone. The dip is from 55 to 60 degrees and the coal seams are extremely variable; but the variations seem to be due only in part to serious disturbance. In the Pechgraben area, v. Sternbach saw 6 well-defined coal seams as well as numerous streaks of coal in the great Franz-Stollen, where the dip is 40 to 50 degrees and the rocks as well as the coal are much shattered. The sandstones have been broken into great wedges, which interlock with similar wedges of shale. The coal seams are thin and often are distorted; but they show variations, which clearly are not due to disturbance of the stratification. The third seam, where first opened at the outcrop, consisted of numerous streaks, one to 3 inches thick; it was prospected for a considerable distance in the hope that these streaks would unite; eventually the mass became 4 feet thick but about one half of the shale still remained. The sixth seam is 9 feet thick in the tunnel, where it has 5 clay partings, in all 3 feet. But this seam, resting on shale with plant remains, is variable; in another tunnel the thickest seam is only 16 inches, while in another it is from 3 inches to 2 feet. One cannot determine in the strongly disturbed area whether the seams are lenticular or not, but there are considerable areas, in which according to the diagrams, there was little disturbance and the succession is normal; in these the lens-form is distinct. The coal is somewhat inferior, having 17.2 per cent. of ash. This Pechgraben coal, according to v. Gümbel,[18] shows woody

[18] C. W. v. Gümbel, "Beiträge, etc.," 1881, p. 160.

structure distinctly after treatment with Schultze's solution; even the minute details can be recognized.

The whole region of the Lias, except locally, is much disturbed, dips of 80 degrees being by no means rare, but the coal throughout contains a high percentage of volatile combustible matter and yields a strong coke. The Grestener deposits are very largely sandstone. No freshwater fossils were noted by any of the observers but there is abundant evidence of repeated invasions by the sea; the marine mollusks belong to off-shore types.

Hungary.—The importance of Liassic coals in Austria, where land conditions became pronounced, prepares one for the great development farther east in Hungary. The coal-bearing formation belongs to the Lower Lias and, according to Hantken,[19] the coals are as important to Hungary as the Carboniferous coals are to England, Belgium, France and Germany, the seams being thick and the coal good. There are five important districts: Doman-Resicza, Steierdorf-Anina, Berszaszka, Fünfkirchen-Uralja and Neustadt-Törzburg; the first three are in the Krassoer Comitate between 39 and 40 degrees of Longitude and between 44 and 45 degrees of North Latitude and are near the Serbian border; the fourth is near the 36th meridian and the 46th parallel, while the fifth is in Transylvania, close to the border of Roumania.

In the Doman-Resicza district the Lias rests on deposits of Dyas age and the dip is from 30 to 90 degrees, at times overturned. Two seams, 40 meters apart, are intercalated in the sandstone mass. The thickness of each is from nothing to nearly 3 meters and the variation is as marked along the strike as along the dip. Each has clay as floor and roof, so that the coal is apt to be dirty.

The Lias sandstone in the Steierdorf-Anina district rests on Dyas. It is 160 meters thick, light in color, is almost clean quartz sand with some mica and little clay or cementing material. There is about 10 meters of other rock, including the coal seams. These thicknesses, according to Hantken, are averages only, for all portions of the section, especially the coal seams, are variable. Eleven coal horizons were seen, of which 5 have workable seams, one to 4

[19] M. Hantken, "Die Kohlenflötze, etc., der Ungarischen Krone," Budapest, 1878, pp. 44–118.

meters thick. Immediately above the lowest seam is a laminated sandstone, carbonaceous and containing many plants of swamp types. The upper part of this sandstone, floor to the second seam, is somewhat argillaceous and holds vertical plant remains resembling roots. The coal seams consist ordinarily of several benches, some of them good, but others worthless. Kudernatch's section at one locality shows (1) upper bench, clean coal, 0.713; (2) earthy, impure coal, a mixture of Faser and bright coal, locally known as "Brand," 0.552; (3) middle bench, clean coal, 1.025; (4) coal and shaly coal, 0.053; (5) lower bench, clean coal, 1.394; (6) impure coal, not mined, has steel-like luster, 0.154; total, 3.891 meters. The coal is in bright and dull laminæ, but the bright predominates. The Hangendflötz also has the Stahlband as faux-mur. The roof and floor of all the seams are shaly sandstone with remains of plants. In the lower coal group, ferns predominate, in the upper group, cycads are abundant. These groups are separated by 97 meters of barren measures and Hantken is inclined to regard the upper one as belonging to the Middle Lias. About 74 meters of bituminous shale overlies the sandstone mass and contains streaks of coal as well as layers of iron ore. Some portions of this shale yield 3 to 7 per cent. of crude oil, from which paraffin and illuminating oil are obtained. The Liassic in this district is apparently of freshwater origin; the variations in thickness of the coal seams are due in very small part to compression, as is evident from the many illustrations given by the author.

Grand'Eury, in the memoir already cited, states that the coals at Anina and Bregeda rest on soils of vegetation. At Bregeda, where the coal is anthracitic, the mur and partings have many roots in place, some of them spreading out under the coal and much divided, while others are erect and cross several layers of the shale. At Anina, where the coal is fat, woody roots are in the mur and herbaceous roots in the partings.

The greatest thickness of coal is in the small area near Fünfkirchen, where the coal group, consisting of alternating sandstones, marly shales, clay shale, coal seams and layers of iron ore, rests on Rhaetic beds and underlies the marine Middle Lias. It is about 800 meters thick. Not less than 180 coal horizons have been recognized,

with 25 to 28 workable seams. The thicknesses vary greatly and, at times, the rapid increase of earthy matter renders an important seam worthless. Mining operations are extensive and the horizons have been correlated closely. The succession of the thicker seams from below upward is

I. and II., 24 to 36 inches, mostly unworkable;
III., IV., VI., 36 to 48 inches, one half to three fourths good coal;
VII., VIII., IX., 24 to 30 inches, occasionally too thin for working;
X., 18 to 24 inches, a hard coal;
XIII. to XIX., 12 to 24 inches, light, caking coal;
XX., 20 to 60 inches, coal similar to the last;
XXII., 0 to 60 inches, often absent;
XXIV. to XXVIII., 20 to 24 inches, coal is hard.

Almost the whole of the formation was crossed in the tunnel at Vasas, where 174 seams were crossed in 717 meters. The total thickness of coal is 52 meters, but one half of it is unavailable because the seams are too thin or the coal is impure. 39 seams, with thickness of somewhat more than 14 meters, are marked as containing dirty coal.

The mining districts are Fünfkirchen, Szabolcs and Vasas. In the Fünfkirchen district, dips are 30 to 50 degrees and seams less than one foot are rarely mined; those of more than 2 feet are usually divided by partings. The mass, numbered XI. and XII. in the Vasas tunnel, consists of (1) clean coal, 0.40; (2) shale, 0.25; (3) clean coal, 0.40; (4) carbonaceous shale, 0.45; (5) clean coal, 0.48; (6) carbonaceous shale, 0.05; (7) clean coal, 0.25; (8) carbonaceous shale, 0.20; (9) clean coal, 1.00; (10) dirty coal, 0.60; (11) clean coal, 0.60; (12) shale, 0.05; (13) clean coal, 0.40; (14) carbonaceous shale, 0.20, resting on sandstone. The roof is shale containing mullusks. Other seams are double or triple and the partings are clay or carbonaceous shale. Of the 512 beds of rock cut by the Vasas tunnel, 8 contain marine fossils; three of them being in the highest portion, 70 meters, a transition to the overlying *Gryphæa* beds. Many marine mollusks have been obtained from the roof of coal III., the floor of XVIII. and the partings of XIII. and XXII. These are *Ostrea, Gervillia, Panopæa, Lima* and other off-shore

genera. Faux-mur and faux-toit are common. The dip is high and the coal is tender; of that mined at Fünfkirchen, only one per cent. is lump, pieces as large as a man's head; 20 per cent. is coarse, 20 millimeters or larger, while the remaining 70 per cent. is "dust"; volatile in this district is about 18, but in the Szabolcs district it is about 23. The coal is black, tender and in great part caking. The gas is low in illuminants.

The flora of Fünfkirchen consists of ferns, cycads and lycopods, some of which seem to persist throughout the Lower Lias. Leaf-bearing beds seldom overlie coal seams.

In the western part of the southern area, that of Neustadt-Törzburg, the coal-bearing Lias rests on crystalline schists and consists of brown, argillaceous, micaceous sandstone, which, through increasing content of plant remains, becomes darker and finally passes into carbonaceous shale, containing streaks of coal. The roof is a quartzose sandstone without trace of plants. In the eastern division, the schists are not reached and the coal group, consisting of sandstones, marls and coal seams, rests conformably on limestones. There seems to be but one coal seam, one to 2 meters thick, but the region is so broken by folding and faulting that a detailed section cannot be obtained.

Hantken called attention in the first edition of his work to the presence of roots in the floor of coal in the Steierdorf region; Zincken,[20] soon afterward, noted that near Kola, in the Steierdorf district the same horizon yields abundance of roots in vertical position. Gothan,[21] having seen the root-bearing underclays associated with Jurassic coal seams on the Yorkshire coast of England, thought wholly probable that similar clays might be present in the Fünfkirchen area. His examination was successful though, owing to physical conditions, it covered only a portion of the district. At one locality, he found under coal VII. a characteristic underclay with irregular branching coaly markings, varying in direction and

[20] C. F. Zincken, "Ergänzungen zu die Physiographie der Braunkohle," Leipzig, 1878, p. 159.

[21] W. Gothan, "Untersuchungen über die Enstehung der Lias-Steinkohlenflötze bei Fünfkirchen (Pecs), Ungarn," *Sitz. k. preuss. Akad.*, VIII., 1910, pp. 129–143.

wholly resembling roots. At another, he discovered a rhizome with its rootlets, which made the relations of the other markings clear. "Through such horizontal rhizomes, the analogy of the Mesozoic underclay with the Carboniferous Stigmaria-beds and the recent or sub-recent reed beds is the more marked." Roots are rarely recognizable in freshly exposed rock but they are sufficiently distinct after slight weathering. Gothan removed the débris for some meters at several horizons and in one day he found well-marked underclays with roots, associated with 8 coal seams. In all, he uncovered such clays under 12 seams.

Spitzbergen.—Nathorst[22] has described a sandstone group midway in his Jurassic of Spitzbergen. It contains coal seams and freshwater mollusks. A coal seam is exposed on the south side of Cape Bohemian, underlying sandstone and resting on shale or shaly sandstone. Leaves abound above the coal, *Ginkgo, Baiera,* with cycads and some ferns, and *Elatides* is under the coal. Bituminous sandstone with plant impressions and a seam of coal was seen at another locality, where, somewhat higher in the section, there is a soft clean sandstone with the same plants as well as freshwater mollusks, *Lioplax* and *Unio;* but still higher is a deposit with fossil wood and marine mollusks. The same group was seen on the shore of Van Keulen Bay, where the lower portion contains some thin coal seams and some clay ironstone.

Siberia.—Coal seams of Mesozoic age are present in extensive areas within Siberia. Their place in the column had not been determined when the description cited was prepared.[23] They were taken to be Jurassic, but they may be in part Rhaetic.

In the region between the Yenisei and Irkutsk rivers, the coal-bearing portion of the Jura, 60 to 90 meters thick, consists essentially of sandstone with subordinate beds of conglomerate and shaly clay. Fat and dry coals are here and boghead is not rare. A small area, about 10 kilometers square, of the freshwater Jura, near

[22] A. G. Nathorst, "Beiträge zur Geologie der Bären-Insel, Spitzbergens, und des Konig-Karl-Landes," *Bull. Geol. Inst. Upsala,* Vol. X., 1910, pp. 362, 363, 365–369.

[23] "Aperçu des explorations géologiques et minières le long du Transsiberien," publié par le Comité Géologique de Russie, 1900, pp. 68, 86–92, 97, 179, 182, 190, 197, 199.

Tcheremkhovo in the government of Irkutsk, shows about 65 meters of friable sandstone, in which are 3 coal seams from a half meter to nearly 3 meters thick. The coal is good, caking and has from 3 to 10 per cent. of ash, though occasionally it has more, in one case, 25 per cent. The sulphur is low.

The Transsiberian railroad crosses the brown coal basin of the Middle Tchoulym River between the cities of Mariinsk and Artinsk. In this basin, embracing not less than 7,000 square kilometers, the rocks, almost horizontal, are sands, argillaceous sands, gravels, sandy or plastic clays, freshwater limestones and coal. The mass is 260 meters thick and contains numerous lenticular seams of brown coal. These have small areal extent, the largest being 2 or 3 kilometers long by a kilometer wide, but the maximum thickness in the lenses is from 2 to 6 meters, though in some instances it is far greater, 14 meters at one locality. The coal ordinarily rests on clay, with an intervening faux-mur, and passes upward into a friable coaly material, resembling peat, on which rests clay or sand. This brown coal is excellent, that from the mined portions of the lenses having barely 3 per cent. of ash, and the quantity in this field is said to be "colossal." Another area of brown coal was seen on the Upper Tchoulym River, but the quality is inferior, there being at times as much as 30 per cent. of ash. In other areas, farther west, some seams of brown coal are very thick. In the extensive region along the Angora River, the coals approach boghead in their general features and they have from 10 to 34 per cent. of ash; but some of the seams yield excellent caking coal.

No Mesozoic coal is reported from the Transbaikal region, where Jurassic deposits seem to be wanting; farther east, in the Upper Amur Basin, some coal seams were observed, which are thin and of no economic importance; but on the divide between the Amur and the Zéia Rivers, Jurassic beds occupy a vast area and consist of gray or greenish sandstones with conglomerates and coal seams. Excellent coal has been obtained from a seam on the Grande-Bira River. In the eastern provinces, rocks were found similar to those of central Siberia, with several seams of coal, one to 2 meters thick and yielding anthracitic as well as caking coals.

New Zealand.—According to Hutton,[24] conditions favoring accumulation of coal existed in New Zealand at several horizons, but only during brief periods. The seams are nowhere thick enough to repay mining. One, 6 feet, is merely carbonaceous shale with numerous streaks of coal.

Alaska.—The Jurassic area of northeastern Alaska was examined by Collier,[25] who made a reconnaissance survey of the Corwin formation, probably Upper Jurassic, between meridians 163 and 165, beyond the 69th parallel. The formation is present at 100 miles farther east and notes by other explorers lead to the belief that it extends far inland; Collier's studies were confined to the Arctic coast line. Lithologically, the formation consists of thinly bedded shales, conglomerates, sandstones and coal seams. Shales predominate, more or less calcareous, gray brown to black and vary from mere mudstone to sandy shale. The sandstones and conglomerates are few and seldom exceed 10 or 12 feet. The pebbles are of quartz and chert, the largest being about 4 inches in diameter. The thickness is at least 15,000 feet and the coal area within the district covers not less than 300 square miles. Mining operations were insignificant and the studies were made almost wholly upon outcrops.

The coal seams appear to be in two groups, Corwin, above, and Thetis, below, separated by a great thickness of barren measures.

The highest seam in the Corwin, 4 feet, 6 inches and without parting, is enclosed in black shale or shaly sandstone. Some thin beds and impure coals were seen in the interval, 1,000 feet, to the next workable seam, which is 5 feet thick and divided by two thin partings of clay. Its roof is shaly sandstone and the floor is hard clay. The next seam, 500 feet lower, is the Corwin, which was opened many years ago, but the opening was inaccessible at the time of Collier's visit, being covered by a great snowdrift. This seam, about 1,000 feet above the bold conglomerate of Corwin Bluff, is said to be 16 feet thick, of which 7 feet are practically clean coal,

[24] F. W. Hutton, "Geology of Otago," Dunedin, 1875, pp. 99, 100; Geol. Survey of New Zealand, Reps. for 1873–74, p. 36.

[25] A. J. Collier, "Geology and Resources of the Cape Lisburne Region, Alaska," U. S. Geol. Survey, Bull. 278, 1906, pp. 27, 28, 37–40.

the rest being so badly broken by partings as to be worthless. The interval to the conglomerate of Corwin Bluff is filled with shale, holding at least 8 coal seams. The cliff could not be reached and the thicknesses of only three could be estimated: 4, 12 and 30 feet. An irregular seam underlies the conglomerate and rests on sandstone; it is in pockets but the coal is good in spite of the distortion. Lower seams were seen in the next 1,000 feet, not distorted, as they are in soft shale, which took up the strains.

Below the lowest seam of the Corwin is a series of barren measures, about 8,000 feet, in which only thin streaks of coal were seen; this overlies the Thetis group, which is reached at 6 miles east from Corwin Bluff and its highest seam is known as the Thetis, 6 feet thick, and opened many years ago. Ten seams were found in the succeeding 700 feet of shale, only two of which are likely to prove important.

This necessarily imperfect record suffices to show that the quantity of Jurassic coal in northwestern Alaska is enormous. Some cannel is said to have been found in the Corwin group, but Collier saw none.

Jura-Triassic.

Generally speaking, it may be said that where the succession is complete, there is always a portion of the column, which is debatable ground, and there is difficulty in determining the boundary between formations. In some cases, unconformities due to folding or to erosion offer evidence on which to base a final determination; but such areas, though large in square miles, often mark only local adjustments, similar to those observed within formations, but which no one regards as important. Occasionally, the matter is complicated by lack of fossil remains. Such is the condition in a great part of Australia, where it has not been possible to divide satisfactorily the great mass between the Permo-Carboniferous and the Cretaceous. Jack and Etheridge[26] recognize a Trias-Jura system in Queensland, which Jack has divided into the Ipswich and Burrum formations.

[26] R. L. Jack and R. Etheridge, Jr., "Geology, etc., of Queensland," 1892, pp. 300–39, 366.

The Ipswich or newer formation occupies an area of about 12,000 square miles in southeastern Queensland and consists, for the most part, of fine conglomerates, grits, sandstones and shales with seams of coal and beds of fireclay. At a few miles south from Brisbane, W. H. Rands saw a mass of coal and carbonaceous shale, 12 to 13 feet thick. The "best" coal is in the lower portion; some pieces of hard bright coal, free from shale partings, contained 24 per cent. of ash. A seam in the same neighborhood shows (1) coal, 4 inches; (2) shale, 2 feet, 2 inches; (3) coal with bands of shale, 1 foot, 6 inches; (4) good, hard coal, 5 feet, 3 inches; (5) shale, 3 inches; (6) fireclay, 2 inches; (7) shale with bands of coal, 5 feet, 6 inches; (8) fireclay, 1 foot, 4 inches; (9) coal, 2 feet; (10) black band, 8 inches; (11) coal, 5 feet, 3 inches; (12) hard sandstone, 2 inches; (13) coal, 4 inches; in all, 24 feet, 11 inches with somewhat more than 14 feet of coal aside from the thin bands of coal in the thick shale division. A piece from No. 11 had 19 per cent. of ash. A shaft in this district cut one foot of cannel and, lower down, a seam of hard and bright bituminous coal, but the sample from it contained 31.61 per cent. of ash. The coals in this district are much broken by partings and high in ash; yet, there were times and places during and in which conditions favoring accumulation of clean coal existed; for a piece taken from a thin bench at one locality showed only 2.5 per cent. of ash.

The type district, that of Ipswich, about 30 miles west from Brisbane, was examined by A. C. Gregory. The best seam near Ipswich is 5 feet, 6 inches thick and contains 3 to 4 feet of coal, of which the best contains about 11 per cent. of ash. Beyond Brisbane River, the seams contain comparatively little coal and that is usually poor; but one of them becomes 4 feet, 6 inches at one locality and its coal has barely 9 per cent. of ash. This seam, however, deteriorates in all directions. This variability characterizes seams throughout the district; a thin seam may be disseminated in a mass of coaly shale, 20 to 30 feet thick. Gregory ascertained that the quality of coal bears some relation to its distance from the northern margin of the field, the ash increasing in that direction—that is, toward the border of the great valley in which the coal measures accumulated.

Going westward from Ipswich along the railway to Toowoomba, one reaches lower members of the formation, which have seams of cannel at many localities; the associated rocks are sandstone and shale. A thick seam on Blackfellow's Creek shows (1) coal, 1 foot; (2) fireclay, 1 foot; (3) coal, 6 feet; (4) white clay, 1 foot; (5) coal, 1 foot; (6) clay shale, 1 foot; (7) coal, 1 foot; (8) a thick bed of fireclay and shale. The coal in all benches is hard cannel, so that the whole of it is available. There are some seams of bituminous coal, caking, in this region but they are thin. Near Clifton station on this railway, a shaft cut three seams at 60, 80 and 100 feet from the surface. The lowest is a rich, very hard "oil coal"; the middle seam yields good caking coal and the highest, 4 to 5 feet thick, consists of bright bituminous to dead-black "oil coal," all being hard and tough. From the description, it would appear that the cannel is in lenses within the bituminous coal. The town of Warwick is on an outcrop of sandstone, which holds a great quantity of fossil wood, usually replaced with iron ore. The coal between Warwick and Walloon is mostly cannel, which yields a high percentage of gas or of oil and paraffin.

The only mollusk recognized is *Unio*. *Vertebraria* is in the underclay of a coal seam near Tivoli. From various horizons, there were collected 11 genera of ferns, 4 of cycads and 5 of conifers.

The Burrum formation or lower portion of the Trias-Jura is exposed in a continuous area of about 3,000 square miles as well as in some small areas. Not much development had been attempted prior to 1892, owing to lack of railroad communication; but comparatively extensive operations were under way near Howard, about 150 miles north from Brisbane. There W. H. Rands measured a section of 1,015 feet, representing the top fifth of the formation and containing 6 seams, 1 foot, 8 inches to 5 feet thick, which were mined. These coals are of good quality, low in ash, are caking and yield a good gas for illuminating. The coal seams generally are irregular. The fauna is scanty, a few specimens of *Corbicula* and of *Rocellaria* have been seen. The flora is almost equally scanty and is represented by a few fragmentary specimens belonging to 4 genera of ferns, 2 of cycads and one conifer.

In New South Wales,[27] strata seen on the Clarence River District have some insignificant streaks of coal and the flora has Jurassic affinities. The rocks are conglomerates, sandstones and shales, and the coal seams are unimportant. The Wianamatta beds, about 700 feet thick, are older and more argillaceous. Entomostraca occur in the upper layers. The coal seams are, at most, only a few inches thick. The Hawkesbury series, resting on the Permo-Carboniferous, is about 1,000 feet thick and consists of yellowish-white sandstone with a few beds of shale and conglomerate and some streaks of coal, without economical importance. The sandstones show much false bedding, usually directed toward the northeast, but reversal of the currents is evidenced by occasional inclination in the opposite direction. Contemporaneous erosion of the sandstones is proved by old channel-ways filled with gravel and angular bowlders are not rare. Wilkinson thought the false bedding due to currents in shallow water; but he cites J. E. Tennison-Woods, who asserts that the peculiar structure is evidence that these sandstones are a wind-blown formation. Plant leaves and fragmentary stems as well as remains of fishes are in both formations but no remains of marine animals had been discovered. The later studies of the New South Wales geologists make it clear that the relations of the Wianamatta and Hawkesbury to the Triassic are very close.

TRIASSIC.

The term Trias is of German origin; on much of the continent, the system is triple or was recognized as triple, being divided into the Keuper, Muschelkalk and Bunter. In later years, the Rhætic or Infra-lias has been taken to be more closely allied to the Trias, so that now the divisions are four.

Within Great Britain, Rhætic, Keuper and Bunter have been recognized, but the Muschelkalk or limestone division seems to be wanting. The several formations consist of conglomerates, shales, marls and sandstones; the Bunter in considerable areas passes downward gradually into the Permian. Rock salt and gypsum are in the

[27] C. S. Wilkinson, "Notes on the Geology of New South Wales," Dept. of Mines, Sydney, 1882, pp. 53–55.

Upper Keuper. The whole mass is apparently without coal. The sandstones in very many cases are false bedded, suggesting wind-drift structures; footprints abound at numerous localities. The general features have led some English geologists to believe that the Trias of that country was formed during desert conditions. On the continent, coal was formed during the Upper Keuper as well as in the Lower or Kohlenkeuper. There appears to be none in the Muschelkalk or Bunter sandstone. Salt and gypsum are in the marls of Upper Bunter, footprints are numerous in the Middle, while the sandstones of the Lower Bunter are usually false bedded and footprints are abundant. As in England, the Bunter of north and central Germany passes gradually downward into the Permian.

Sweden.—Coal is present in the Rhætic of Sweden. Hebert[28] states that at Ramloesa, 4 or 5 kilometers southeast from Helsingborg, he measured a section of somewhat more than 240 feet, consisting mostly of black shale, with a streak of coal, 2 centimeters, at the top, and another, 3 decimeters, at the base. The latter was mined. The shales associated with this coal yielded no plant remains to Hebert, but other collectors had obtained specimens, which are in the museum at Lund. Plant impressions were seen in a sandstone, midway in the section. Plant structure is distinct in the coal. Geikie,[29] summarizing results obtained in this region by Nathorst, E. Erdmann and G. Lindstrom, says that the area of these Rhætic beds is about 250 square miles. They have been divided into a lower, freshwater group, containing workable coal seams, and an upper, marine group with only poor coal but abundant marine organisms. Clay ironstone occurs in the lower group and beds of fireclay underlie the coal seams.

France.—Servier[30] described the Keuper area of the Vosges, northeastern France. The Upper Keuper is triple; variegated marls on top, dolomitic limestone in the middle; the lower division is (1) variegated marl, 1.50; (2) micaceous sandstone, more or less

[28] E. Hebert, "Notes sur les grès infraliassiques de Scanie (Suede)," *Bull. Soc. Geol. France*, II., Vol. 27, 1870, pp. 366–376.

[29] A. Geikie, "Text-Book of Geology," 3d ed., 1893, pp. 870, 871.

[30] M. Servier, "Notes géologiques sur les mines de houille de Norroy (Vosges)," *Bull. Soc. Ind. Min.*, t. IV., 1858–59, pp. 384–398.

argillaceous, with abundant impressions of plants and animals, 3.30; (3) laminated shale, argillaceous, with leaf impressions, 0.05 to 0.15; (4) coal, 0.25 to 1.00; (5) black-brown carbonaceous shale, with great abundance of vegetable impressions, ill-preserved but remarkably like modern swamp plants, such as reeds and ferns, 0.50; (6) marly shales with plant impressions and *Posidonia,* 0.90; (7) shaly sandstone with remains of plants, 0.50; (8) silicious fetid limestone, 3.00; total, 10.40 meters. This rests on the Lower Keuper, mostly variegated marls with gypsum and salt. The dolomite marks a notable change in conditions; below it, the deposits are micaceous and sandy, with abundant remains of plants and animals; but above it, marls predominate and remains of any sort are rare.

The coal seam varies greatly in thickness; at times it bifurcates, at others it disappears. These variations are not due to disturbance as the dip is less than 3 degrees. Kidneys of dark calcareous iron ore are in the coal, now concentrated under the roof but again scattered throughout the seam. Pyrite is abundant. Where thickest, the seam is triple, showing (1) upper bench, variable, consisting at times of alternating bright and dull laminations, when the coal is rejected as it burns badly and is not reduced to ash; commonly, however, it is brilliant black and an excellent fuel; (2) middle bench, not always present; its coal is glossy black, is almost uniform, burns well and is reduced to red ash; it encloses vegetable remains, some of them root-like; (3) lower bench, has brilliant black coal, yielding a brown powder.

The quality and thickness improve toward the north. At the south, near La Marche, Romain and Talliancourt, it is replaced with clays containing great numbers of tree stems. Mining begins farther north near la Rouville and Croinville, where the thickness is 0.15 to 0.30; at Norroy, it becomes 0.40 to 0.80, but at Gemmalaincourt and Parey it is 1 meter. Fragments of shale, quartz and sandstone with rounded angles occur occasionally in the coal. The lenticular form of the seam is distinct.

The same horizon has been recognized at widely separated localities in France, though coal is rarely present. Rouville,[31] describing

[31] P. de Rouville, *Comptes Rendus,* t. 48, 1857, pp. 696–698.

the Trias of Aveyron and Herault, states that the abundant coaly impressions of plants in Keuper beds had induced many to search for coal but without success. Grand'Eury saw some coal in the Keuper of Nice which contains stems of *Equisetites* and in the shale are rootlets of these plants. At Gemmalaincourt, he found *Equisetites* roots in the underclay but bark and seeds are in the coal.

Germany.—The Lower or Kohlenkeuper contains at many places in Germany the Lettenkohle, which Credner[82] describes as a carbonaceous clay, filled with plant remains and at times passing into impure coal. Near Siwierz in Poland there are 3 beds 30, 50 and 80 inches thick. Sandberger[83] published records of numerous sections of Triassic deposits obtained in Unterfranken of Bavaria. He offers no comments, but the records suffice to prove irregularity of deposit. Two Lettenkohle sections near Würzburg exhibit the triple structure. That obtained between Würzburg and Rothendorf shows at top of the middle division a yellow fine-grained sandstone with many erect roots, while at base of the division is a zone with abundant remains of plants. This rests on the Hauptsandstein of the lower division, part of which is diagonally bedded. No coal is present. In the other section, between Würzburg and Schweinfurt, plant remains abound in both the upper and the middle division, but coal is wanting; the top layer of the Hauptsandstein is argillaceous sandstone with many roots, while at the base is a fine-grained sandstone with irregular layers of pulverulent coal. A section of the Krainberg gives these details respecting the middle division: (1) clay shale, with Lettenkohle at base, 3.66; (2) shale, 0.15; (3) sandstone with roots, 1.18; (4) clay shale, 1.18; (5) Lettenkohle and plants, 0.70; (6) ochreous limestone, 1.32; below which to the base are sandstone, ochreous limestone, clay shale and sandy shale, all apparently without coal. The sandstone, No. 3, is the root bed for plants which produced the impure coal above it.

The conditions seem to have been much the same at all localities where Lettenkohle exists. The coal is irregular in occurrence and

[82] H. Credner, "Elemente der Geologie," 8te Aufl., 1897, p. 535.

[83] F. v. Sandberger, "Die Lagerung des Muschelkalk- und Lettenkohlen Gruppe in Unterfranken," *Verh. Phys. Med. Gesells. Würzburg*, Band XXVI., 1893, pp. 200, 205, 206.

usually is of little value. The influx of foreign matter into the petty swamps was too great to permit accumulation of clean coal; but root-bearing underclays and soils of vegetation without coal are characteristic features. v. Gümbel[34] states that Lettenkohle from Guildorf in Würtemberg and Schweinfurt in Franken gives a weak brown tint to solution of caustic potash; it is easily decomposed by Schultze's solution and woody structure is distinct in the residue. Rhætic coal from near Bayreuth reacts to Schultze's solution as does Lettenkohle. Many layers of this coal appear to consist almost wholly of pollen exines.

Austria.—An important area of Triassic coals is in Upper and Lower Austria; these belong to the Lunzer beds of the Upper Keuper. A less important area is in Südtirol, where coal is in the Wengener beds at the base of the Keuper.

The Upper Keuper area was studied by Lipold[35] and his associates. The Triassic deposits are in the interior of the northeastern Alps and they have suffered more from disturbance than have the Liassic beds of that region. Lipold reports that near Baden, on the eastern side of the area, the coal and shale are so crushed and intermingled that definite sections cannot be made and that all attempts to obtain merchantable coal have failed. No mollusks were seen but *Calamites arenaceus* and *Pterophyllum longifolium* are not rare.

Hertle found only unimportant seams in the Lunzer sandstones near Ramsau; but in Kleinzell, where the sandstone is much distorted, 3 thin seams were seen, all marked by extreme variations in thickness, which seem to be due to compression during folding. At Lilienfeld on the Traissen River, the dip is from 40 to 70 degrees and the coal seams, being between sandstones, have been distorted seriously. The thickness of one seam varies from one inch to 9 feet within a short distance. The Lunzer sandstone is distinctly of freshwater origin in this district, but it is between the Opponitzer above and the Goslinger below, both of them calcareous and containing marine fossils. The workable coal seams, 4 and 2 feet thick,

[34] C. W. v. Gümbel, "Beiträge, etc.," p. 160.

[35] M. V. Lipold, G. v. Sternbach, J. Rachoy, and L. Hertle, "Das Kohlengebiet in den Nordostlichen Alpen," *Jahr. k. k. Geol. Reichs.*, Band 15, 1865, pp. 62–159.

are in a mass of black shale, about 70 feet thick. *Equisetum columnare* is abundant in the black shales and beautiful specimens have been obtained from the roof of the upper seam. This seam, 4 feet thick where first seen, is from 3 to 24 feet. Occasionally it divides into two or more benches, of which only one is persistent. The coal of Lilienfeld and Kleinzell yields 72 to 74 per cent. of good coke and ash is from 8 to 14 per cent. in the raw coal.

Hertle examined the area near Kirchberg on the Pielach River where the black shale mass has 4 seams of coal. This shale is 40 feet in one tunnel, 48 to 60 in another, while in a third it is not less than 100 feet. In one tunnel, the middle seam is 72 feet above the lower one; followed westward, the interval becomes 50, 30 and 18 feet. A similar convergence is that of the middle and upper seams, which actually unite with increased thickness. These relations existed before disturbance occurred. Dips in this district are from 40 to 70 degrees. The coal throughout is tender and caking, giving 67 per cent. of good coke; but the ash is high, averaging 15.8 per cent. In the Rehgarten area, the coal is cleaner, having only 9 per cent. of ash. Here distortions of the rocks are few but other troubles are encountered; the seams thin away and frequently they pass into carbonaceous shale. Hertle's descriptions make it clear that the seams are lenses, sometimes joined by carbonaceous shale, but at other times wholly separate. The "horseback" seems to be a feature here, as in the older as well as in the newer coals. One tunnel reached sandstone, with no admixture of clay or coal, at 480 feet from the mouth. It was pushed through the rock and again reached the coal. The lower seam at Loichgraben yields a good coal, but that from the upper seam has 52 per cent. of ash, though it looks like excellent coal.

Rachoy found plant-bearing shales as roof of coal seams near Lunz and he says that, near St. Anton, a bituminous limestone is the roof in some mines. The coal at several localities is good but at others the ash is very high, while the coal externally resembles the best in the district. This area is on the westerly side of the Lunzer region and, in most cases, the seams are thin.

Zincken[36] states that plant-bearing shales are the roof at many

[36] C. F. Zincken, "Ergänzungen, etc.," 1878, pp. 110, 111.

localities; that the coal seams are distinctly lenticular in some of the important districts, and that the coal is caking at some places, but non-caking at others.

The Wengener beds are at base of the Keuper and rest on the Muschelkalk. Keyserling[37] found coal within these beds, west from Cordeville Valley on the southeasterly slope of Mt. Cordai in south Tyrol. The rocks are alternating tuff sandstones, red, green and brown clays and marls, interrupted by beds of limestone. All yield so readily to the weather that a detailed section cannot be made. The Hauptflötz, locally regarded as "workable," is from 4 to 5 decimeters thick and is well exposed in the bed of a stream, where it rests on dark limestone; elsewhere, it is frequently enclosed in clay and sandstone. The coal is laminated, some of it resembling brown coal but other portions are much like stone coal. The transformation is so far advanced that no trace of organic structure can be recognized by the naked eye, but the mode of occurrence convinced the author that it was derived from water-loving plants. The quantity of pyrite is remarkable. Coal rarely occurs at this horizon.

The Lunzer horizon was recognized by Lipold[38] in Carniola (Krain) who saw near Idria coaly shale with streaks of coal, but he could discover no definite seams.

Hungary.—Hantken[39] reports that in the Fünfkirchen region of Hungary a sandstone formation, 620 to 950 meters thick, underlies the Liassic coal complex conformably. Its coals appear to be local and in most cases they are too thin to be mined. Fossils are not abundant; at one locality, *Zamites, Palissya* and *Thaumatopteris* have been collected; another yielded *Cardinia* and *Acrodus.* This assemblage is accepted as evidence that the mass is of Rhætic age.

United States.—Triassic deposits of the Atlantic border extend in detached areas from Massachusetts to North Carolina. No coal of economic importance has been discovered north from Virginia, though thin streaks have been observed in Massachusetts, Rhode

[37] H. G. Keyserling, "Ueber ein Kohlenvorkommen in den Wengener Schichten der Südtiroler Trias," *Verh. k. k. Geol. Reichs.*, Jahrg. 1902, pp. 57–61.

[38] M. V. Lipold, *Jahrb. k. k. Geol. Reichs.*, Band 24, 1874, p. 445.

[39] M. Hantken, "Die Kohlenflötzen, etc.," pp. 104, 105.

Island and Pennsylvania. McCreath[40] states that P. Frazer had found coal in Triassic beds of York County, Pennsylvania, but neither he nor Frazer in his York County report gives a description of the deposit. According to McCreath, the coal is deep black, with pitchy luster, brittle and with conchoidal fracture. The proximate composition is: Water at 225° F., 4.310; volatile, 18.482; fixed carbon, 74.358; sulphur, 0.528; ash, 2.322. There is no tendency to cake and the gases burn with non-luminous flames. The dried coal absorbs water with great avidity, so that within a few hours it re-absorbs about 63 per cent. of the water originally present.

The important region known as the Richmond coal field is reached at a little way north from the James River in Virginia. Mining operations were begun a century ago and for many years they were on extensive scale. Irregularities in the seams and the many faults made mining costly and the local coal was displaced by anthracite from Pennsylvania. Operations now are unimportant.

Fontaine,[41] in the introduction to his descriptions of fossil plants obtained in the Richmond and adjacent areas, gave a synopsis of the relations. The Triassic rocks occupy several areas in a belt extending from Rhode Island to South Carolina. The most westerly area, termed the Palisade, is almost continuous from the Hudson River across New Jersey, Pennsylvania and Maryland to about 75 miles southwest from the Potomac River in Virginia; it is without coal. The small area of Buckingham County, Virginia, is east from the last and like it is without coal. The Dan River area, still farther east, is in Virginia and North Carolina; it has some coal in the latter state. The Cumberland (Farmville) area is small but has some coal seams of local importance. The Richmond, 30 miles east from the Cumberland, is the last in Virginia, but the Deep River, still farther east, is in North Carolina and extends to the South Carolina border.

Red beds prevail in the western areas but they are insignificant in the Cumberland and Richmond areas. Fontaine recognized three

[40] A. S. McCreath, Second Geol. Survey Penn., Report MM, 1879, p. 103.

[41] W. M. Fontaine, "The Older Mesozoic Flora of Virginia," U. S. Geol. Survey, Mon. VI., 1883, pp. 1–7, 12–16, 32, 45, 79.

distinct groups in the Virginia areas: the upper group, consisting of loose granitic sandstone or sandy shale, containing no coal but much lignite, resembling jet; silicified wood is not rare; a middle group, coal-bearing, with a large proportion of black shale; a lower group, sandstone and shale. The sandstones of the lower group are not easily distinguished from the underlying granitoid gneiss and are 100 to 600 feet thick in the Richmond area. The middle group is 100 to 200 feet thick in the same field, where it usually has two thick seams of coal—but the number, thickness and quality vary greatly. At many places the roof is a plant-bearing shale; *Equisetum rogersi* is usually associated with *Macrotæniopteris* and its casts are present in the coal. *Schizoneura* occurs in the underclay of the main seam. The plants described by Fontaine are conifers, cycads, equiseta and ferns.

Shaler and Woodworth[42] applied names to Fontaine's groups; the Chesterfield or upper group is 2,500 feet thick and consists of sandstone above, shales below; the Tuckahoe, equivalent to the middle and lower groups, consists of the coal measures, 500 feet, more or less, sandstones and shales, 0 to 300 feet, and bowlders, 0 to 50 feet.

The Richmond field was discussed many years ago by geologists, who studied it when the mines were still in operation.[43] It is well to summarize the statements of each observer as the conclusions reached by them have been regarded as not in agreement and they appear to be in some respects contrary to those reached by observers who have studied the region since mining operations practically ceased.

Taylor reported that the deposits occupy a narrow trough, which deepens so rapidly toward the median line that coal mines are pos-

[42] N. S. Shaler and J. B. Woodworth, U. S. Geol. Survey, 19th Ann. Rep., Part II., 1899, p. 423.

[43] R. C. Taylor, "Memoir of a Section Passing through the Bituminous Coal-Field near Richmond, Virginia," *Trans. Geol. Soc. Penn.*, Part I., 1835, pp. 275–297; W. B. Rogers, "Reprint of Annual Reports on Geology of Virginia," 1884, pp. 62–69; "On the Age of the Coal Rocks of Eastern Virginia," *Reps. Amer. Asso. Geol. and Nat.*, 1843, pp. 298–316; C. Lyell, "A Second Visit to the United States of North America," 2d ed., London, 1850, pp. 281–287.

sible only on the eastern and western margins. The maximum thickness of coal, as far as can be ascertained, is near the middle of the eastern border, whence it thins toward the north and the south. The coal in all mines, of which Taylor gives measurements, is near the base of the section and rests on the granite or is separated from it by, at most, a few feet of shale. The overlying rocks, for about 400 feet, as cut in shafts on both sides of the trough, are mostly grits, sometimes conglomeratic, with interstratified gritty micaceous, carbonaceous or argillaceous shale.

In the northeastern part of the trough, he saw two seams, 5 and 3 to 4 feet, separated by 10 or 12 feet of slate and about 10 feet from the granite, there being a thin seam in the latter interval. On the northwestern side, the seams are 30 feet apart and are 6 to 16 and 4 to 8 feet thick. These are said to unite farther north. The lower seam, of rather inferior quality, rests on the granite. On the eastern border, the Chesterfield shaft shows (1) coal shale, 6 feet, 10 inches; (2) coal, 5 feet, 6 inches; (3) coal shale, 3 feet; (4) coal, 1 foot, 6 inches; (5) hard grits, 2 feet, 6 inches; (6) shale and thin coal, 2 feet, 6 inches; (7) coal, 7 to 40 feet; (8) granite. The lowest coal has some variable partings. The sections on this side of the trough are much alike; but the coals, 4 and 6, are not always present and not infrequently some shale was seen between the coal and the granite.

As the mines had been worked extensively prior to Taylor's visit, he had opportunity to examine considerable spaces from which the coal had been removed so that the underlying granite surface was exposed. Not rarely a boss of granite rose through the lower division of the seam; in such cases, the work was usually abandoned; but occasionally a drift was carried around the boss and entered a body of coal, filling a hollow, 50 or 40 feet deep. There is no parallelism between top and bottom of the seam. The roof is irregular, rising and falling, and the depressions sometimes reach the floor, but they never conform to the irregularities of the granite surface. In spite of these irregularities, the lamination of the coal is wholly undisturbed. The lower part of the seam is less clean than the upper, but the coal is fat and coking throughout.

Rogers was studying the region at the time of Taylor's visit.

His report, published in 1836, contained a brief statement which adds important observations while confirming those made by Taylor. He discovered that the overlying sandstone group apparently overlaps the coal measures and that the lowest coal seam is separated from the granite in most cases by only a few feet of shale. The coal thickens toward the center of the basin and, as a rule, the higher seams are the best.

In the Midlothian and several adjacent mines, there is ample evidence to prove that the coal accumulated in saucer-shaped basins to the thickness of 40 or 50 feet, while on the eminences of the same floor it is thin. On the south side of the James River, the River pit was abandoned when the granite floor rose almost to the sandstone roof. Near Tuckahoe, on the north side of the river, the coal was found central in a small, isolated, cup-like depression. This coal rose gently in all directions from the shaft and thinned from 5 to 2 feet toward the edges of the shallow basin. This is several hundred feet in diameter and its strata vary little from the original nearly horizontal position. "Everything lends countenance to the opinion that the surface of the primary rock, previous to the deposition of carbonaceous matter, was a valley of rolling outlines, occupied by hollows and elevations, causing the first layers of matter, which were thrown down, to be deposited in greater thickness in some places than in others. As the lowest coal seam is separated from the crystalline rock by only a very few feet of shale and in some cases by none at all, it appears likely that the distribution of the coal was made unequal in thickness from the very commencement."

In his later memoir, discussing the relation of the plant remains, Rogers stated that the most abundant plants are *Equisetum columnare, Tæniopteris,* and a large species of *Zamites.* These occur in vast numbers immediately upon the coal or interlaminated with it. They are accompanied by *Calamites, Pecopteris* and *Lycopodites.* The *Equisetum* is so abundant, at times, as to give a coarse coal consisting of alternate laminations of coal and shale with occasionally 30 laminations to the inch. Ferns are rare, aside from the great *Tæniopteris.* The only animal remains are those of fish and some teeth supposed to be reptilian. The fish remains are in dark

shale associated with the coal; but scales along with teeth and plant impressions were seen at times in the upper part of the coal itself. Rogers saw nothing answering to the *Stigmaria*-clay of the Carboniferous. These descriptions by Rogers make clear that a faux-toit is the ordinary feature; while the presence of animal remains in the coal indicates existence of pools on the swamp surface. Underclays are in this field, but they do not hold *Stigmaria,* for *Lepidodendron* and *Sigillaria* had become extinct.

Lyell visited this field in 1845. He was much impressed by the fact, already noted by Rogers, that stems are found so often erect and compressed vertically; he could think of no reason to doubt that the greater number of such plants, in beds above and between coal seams, and which he saw at localities miles apart, had grown where they are now enclosed in sand or mud. The great coal seam rests at times directly on the granite, but at others is separated from it by an inch or two of shale. He was inclined to think that the absence of deposits between the coal and the granite may be due to disturbances, which were considerable, as shown by the extensive faults.

Mining operations ceased at nearly all localities about 50 years ago and the old mines, abandoned, soon became inaccessible. A long interval passed before new studies were made and few[44] of these dealt with details respecting the coals. Fontaine's detailed stratigraphical work was done near Clover Hill in the southeastern part of the field, where some work was going on at the time of his examination. There he found thick deposits between the coal and granite and assigned to them a thickness of 100 to 600 feet. Clifford stated that in outlying districts of the Richmond basin there is only one coal seam, usually of great thickness and separated from the granite by a thin bed of shale, often not more than a few inches. This refers to the northern part of the field. It should be noted here that the earlier observers regarded the benches of coal as separate seams.

[44] W. M. Fontaine, "The Older Mesozoic Flora of Virginia," U. S. Geol. Survey, Mon. VI., 1883; W. Clifford, "Richmond Coal Field, Virginia," *Trans. Manch. Geol. Soc.,* Vol. XIX., 1888, p. 320; I. C. Russell, "The Newark System," U. S. G. S. Bull. 85, 1892, pp. 38–40, 63; N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. G. S., Part II., 1899, pp. 423–426, 429, 483.

Russell asserts that the coal seams of the Richmond basin are irregular and greatly disturbed by faulting. They are not continuous though they are approximately at the same horizon. He regards them as overlapping lenses, individual deposits thinning away. A thin seam in one mine may be the important one in another. As to the interval to the granite, he cites O. J. Heinrich, who in 1879 reported that at Midlothian the coal is at 570 feet from the granite; also Fontaine, who in 1883 stated that the interval at Clover Hill is 250 feet. Russell suggests that the luxuriant subtropical vegetation of these Triassic lowlands has its nearest modern analogue in the fern forests of New Zealand. The ground must have been covered with ferns, above which rose equiseta and the great ferns with palm-like leaves; cycad forests with pines of Araucarian type covered the upland.

Shaler and Woodworth report that the lower barren beds, underlying the coal measures, are not always recognizable with certainty; sometimes the barrenness may be due to lack of coal accumulation at the locality, but there are places where the coal group is fully developed and where a considerable thickness of barren rocks was seen. These authors offer no explanation of the origin of the bowlder beds occasionally observed at the base of the section. They consist of granitic bowlders with a partial bedding of reddish gritty sandstone. Plate XXI. of the report illustrates well the disintegration of the granite, which proceded deposition of Trias in this basin. This is remarkably similar to conditions observed by the writer in central France between Aurillac and Decazeville, where such disintegration is shown at many places. In the Decazeville basin, this preceded the deposition of the Coal Measures and the accumulations were mistaken for deltas by several observers.

Some have supposed that the great variations in thickness of the Richmond seams were caused by pressure during disturbance; but there appears to be no reason for resort to this explanation. Such swelling and contraction of seams is certainly common enough in disturbed regions, but there the structure of the coal is changed; it is exceedingly tender or it is rolled into flakes like pastry. But in the Richmond basin the lamination, according to Taylor and according to observations by the writer, is undisturbed in locali-

ties where the coal is very thick. Several observers have urged that the varying interval between the coal and the granite floor is likewise a result of disturbance. This suggestion may, perhaps, prove good for some localities but to the writer it seems unnecessary to resort to that hypothesis; Rogers's suggestion is far better, that the deposits were made on an irregular surface. This accords with the conditions observed in North Carolina as well as in Virginia.

Two Triassic areas are in North Carolina; the Dan River, at the northwest, is without coal in Virginia but has some irregular deposits in North Carolina; the Deep River, at the southeast, begins near the Virginia line and extends as a narrow strip southwestwardly into South Carolina.[45]

Emmons's section in the Deep River area shows a triple structure: Upper red sandstones and marls; Coal measures, slates, shales and drab sandstones; Lower red sandstone with conglomerate at base. The red rocks, wanting in the Cumberland and Richmond areas of Virginia, reappear here on the southeasterly border. The middle group, about 1,200 feet thick, has fine-grained sandstones which frequently are rippled; the coal seams are few and very irregular but some of them have been opened. Russell states that at Egypt a shaft reached, at 422 feet from the surface, a coal seam showing (1) black shale; (2) coal, 2 feet; (3) black band, 1 foot, 4 inches; (4) coal, 1 foot, 1 inch; (5) slate, 6 inches; (6) coal, 7 inches. Another seam, 25 feet lower, has black band roof and floor and is one foot thick; the upper seam has black shale roof and floor. Both are irregular in thickness and Russell asserts that there is no reason to suppose that they are continuous in any considerable area.

The coals are indefinite within the Dan River area. Emmons reports that, near Leakesville in northern part of the area, a coal seam shows: (1) coal, semibituminous, 2 to 3 feet; (2) micaceous shale, 2 feet; (3) coal, shaly, 1 foot, 6 inches. This is very near the base of the coal group. The lowest rock at the southern extrem-

[45] E. Emmons, "Geological Report of the Midland Counties of North Carolina," 1856, pp. 228, 230, 235, 256, 257; I. C. Russell, Bull. 85, p. 41; W. C. Kerr, "Report of the Geological Survey of North Carolina," Vol. I., 1875, p. 143; R. W. Stone, "Coal on Dan River, North Carolina," Bull. 471–B, 1812, pp. 5, 6, 16.

ity, near Germanton, is a conglomerate of angular fragments of granite and gneiss, containing roots of silicified tree-stems penetrating and branching in the deposit. The stems are very abundant just above the conglomerate, so abundant as to suggest that they are remains of an ancient forest. Most of them are prostrate and occasionally one finds the roots converted into lignite. The great abundance of stems near Germanton in Stokes county impressed Kerr, who says "the public road being in a measure obstructed by the multitude of fragments and entire trunks and projecting stumps of a petrified Triassic forest; and similar petrifactions are abundant in the Deep River belt, occurring in this as in the other among the sandstones near horizons of the coal."

Stone's examinations led him to assign a thickness of about 7,800 feet to the deposits within the Dan River area, where the mass rests on Archean gneiss. The zone of carbonaceous shale with coal is 250 feet thick and just below it, at about 1,000 feet from the base, is conglomerate with subangular fragments, which is absent from the northern portion of the area. The roots and bark of the silicified stems within this mass in some cases have been converted into lignite. Shafts have been sunk in many places but usually only black shale has been found. At one place, 37 inches of such shale with much coal was found. The Leakesville deposit is insignificant and its area is but a few square rods.

Triassic rocks are exposed in very many localities west from the 105th meridian to the coast but they appear to be without coal in both the United States and in the Dominion of Canada.

Mexico.—But coal is present in Triassic deposits of the Santa Clara field on the eastern border of Sonora, Mexico. Dumble[46] has given brief notes respecting the locality. The Rhætic age of the deposits was recognized by Newberry and Fontaine after study of the plant remains. The region has been disturbed greatly by igneous rocks, which have metamorphosed the coals. The heavier sandstones are uniform and are moderately coarse conglomerate grits, which have a few fragments of silicified wood and occasional imprints of stems. The shales and finer sandstones are excessively

[46] E. T. Dumble, "Triassic Coal and Coke of Sonora, Mexico," *Bull. Geol. Soc. Amer.*, Vol. X., 1900, pp. 10–14.

variable, sandy shales change abruptly into coarse massive sandstone or into clay shale. The shales generally are rich in well-preserved remains of plants, which, according to Fontaine, are allied to those of Virginia and North Carolina. The more massive slates hold silicified stems and branches of shrubs, while the finer-grained sandstones have tree-trunks up to one foot diameter. No false bedding was observed in the sandstones.

Coal seams are numerous, each prominent slate bed having one or more; but in all cases these are irregular. Near San Marcial, southeast from the area of detailed examination, much work had been done on supposed anthracite, which proved to be only black slate; but at localities north and northwest from the mining center two seams are known, 8 and 10 feet thick. Much of the thicker beds is composed of coal with concentric structure, "shelling out into eggs of greater or less hardness."

The coal has been affected by the igneous rocks and usually it is a hard anthracite, though occasionally it is coke. In two important openings on the coke, igneous rock is the roof; in another, it is the floor; but other pits show no igneous rock anywhere near the coke. In one seam of anthracite, there are pockets of coke near the middle, while in a seam of coke pockets of anthracite were found at the bottom. In several beds divided by partings, coke prevails in some benches, anthracite in others. The proximate composition of the anthracite is: Water, 4 to 8; volatile, less than 5; fixed carbon, 76 to 85; ash, 4 to 8 per cent.

Some Chemical Features of the Coals.

Coals of various grades are present in the Jura and Trias. Lignite and bituminous coal are present in the Lower Oölite of Great Britain within practically undisturbed rocks and at nearly the same horizon; while high-grade bituminous coal prevails in the Lias of Austria and Hungary, where the rocks have suffered severe disturbance. The Lower Lias of Siberia yields high-grade bituminous in the Tcheremkhovo and Grande-Bira fields but typical brown coal in the great Tchoulym region, where the strata are little disturbed and the rocks are only slightly consolidated. The Jura-

Triassic coals of Queensland are high-grade bituminous as are those from the Upper Trias of Austria and Virginia.

Cannel has been reported from the Jura of Alaska, but Collier saw none. Cannel, however, is certainly present in the Steierdorf-Anina field of the Hungarian Lias. Hantken has given the proximate analysis of two samples from the Hauptflötz, which show

Moisture	1.10 2.60	Volatile	53.77 55.91
Ash	14.67 22.00	Fixed carbon	46.23 44.09

The cannel is evidently in lenses, as at other localities this seam has only bituminous coal. In the same field, the Middle(?) Lias has a great mass of black shale, portions of which yield from 3 to 7 per cent. of crude oil, from which paraffin and illuminating oil are obtained. In Siberia the Lower Lias coal of the Angora River field is mostly of boghead type, while in the Ipswich or upper Jura-Trias of Queensland cannel or "oil coal" is present in a large area. Jack has given three analyses of the material:

	Ash.	Volatile.	Fixed Carbon.
Blackfellows Creek	17	56	43
Clifton, top seam	10	53	46
Clifton, lower seam	16	55	44

The seams at Clifton are separated by a considerable interval, which holds a seam of caking bituminous coal. Cannel prevails in the Walloon district where some of it is rich, that at Jimbour yielding about 37 gallons per ton.

The coals vary greatly in tendency to cake. Collier reports that none of the Alaska coals tested for him gives a coke. His samples, however, were collected mostly from outcrops, where leaching had been energetic during a long period. "Crop coal," even in the Connellsville region of southwest Pennsylvania, yields only a wretched coke. In Austria and Hungary many seams have caking coal but that from others is non-caking. In Siberia, the coals of the Tcheremkhovo and Grande-Bira fields are caking but that of the great Tchoulym field gives only pulverulent coke. The Jura-Trias coals of Queensland are caking in some instances, non-caking in

others. The Upper Trias coals of Austria are usually caking and those of the Richmond area are always so. Apparently no relation exists between proximate composition and tendency to cake.

No reference to the presence of resins in coals of the Jura or Trias is made in any of the works to which the writer has had access. One observation by Witham, cited by Miller, bears upon the subject. In studying silicified stems of *Pinus eiggensis* from the Lower Oölite of Scotland, he discovered that the wood abounds in turpentine vessels or lacunæ, well defined and varying in size.

Mineral charcoal (Fusain, Faserkohle) is a characteristic feature throughout. At times, it forms thin partings in seams, but at others it is an important constituent of thicker partings, where its abundance suggests that the partings are merely residues from a considerable mass of peat. Occasionally it is in lumps, embedded in the coal or in a clay parting.

Sphærosiderite or clay ironstone is reported by all except a very few observers. It is present in the coal, in the underclays, and is scattered in the other rocks, while occasionally it is in layers of varying thickness. At times, it replaces the stems of trees or fragments of wood. Black band layers, associated with seams of coal, have been reported from the Ipswich formation of Queensland and from the Rhætic of North Carolina.

The Jurassic coals of Great Britain are lignite or very low grade bituminous. No analysis of the coals in France is available. The analyses of the Austrian coals, as officially given, are incomplete and afford no information for comparisons; but the coals are clearly high grade bituminous, for that of many seams is caking. Hantken has published many analyses of the Jurassic coals in the Steierdorf-Anina and Fünfkirchen areas, and Nendtwich made a number at a much earlier date. The Steierdorf-Anina samples have as proximate composition:

The low percentage of ash makes evident that the analyses are of specimens supposed to represent the average best coal from the mines. This, however, is unimportant here. The upper Liegendflötz is separated from the higher bed by about 300 feet of rock. No marked tendency to decrease of volatile downward is recognizable

	Water.	Ash.	Volatile.	Fixed Carbon.
Hangendflötz	1.94	1.72	33.77	66.23
	2.50	1.75	36.59	63.41
	1.55	3.10	32.47	67.53
Hauptflötz	1.74	1.28	35.04	64.96
	1.88	2.07	30.41	69.59
	2.10	7.26	39.94	61.06
	1.90	1.95	34.98	66.02
	1.70	2.21	30.22	67.78
I. Liegendflötz	2.25	2.56	32.23	67.77
	2.25	16.78	23.28	76.72
	2.25	2.56	29.22	70.78
	1.85	12.88	42.73	57.27
II. Liegendflötz	2.05	4.19	34.64	65.36
	1.85	3.44	30.77	69.23
	1.75	5.65	41.86	58.13

in this series. The samples from the lower seams, containing the high volatile, must be considered as consisting in part of cannel.

The analyses of the coals from the Fünfkirchen area, published by Hantken, are ultimate; reduced to pure coal, as were those from the Steierdorf area, they are:

Seam.	Water.	Ash.	Carbon.	Hydrogen.	Oxygen.
II.	1.50	24.93	89.6	4.5	5.8
IV.	1.10	13.03	81.6	4.3	14.0
VI.	1.10	5.10	88.1	4.6	7.2
XI.	1.58	7.80	91.7	4.3	3.9
XIV.	1.80	15.77	93.7	4.5	1.7
"	3.20	11.64	77.7	4.7	18.1
XVI.	1.00	13.67	93.4	4.6	1.9
"	5.44	7.28	85.7	4.3	9.8
XXIII.	1.60	15.45	82.9	4.2	12.8
XXIV.	2.70	9.85	86.0	4.7	9.2

The order is ascending. The sulphur is from 1.07 to 6.88 per cent.; but in the great mass of seams XI. and XII. it does not exceed 2.50. In IV. at Vasas there is but 1.23 but at the Colonie mine it is 6.88. The thickness of the seam and the proportion of sulphur are not in relation; some thin beds have little, others much. The coal of XII. yields a great quantity of illuminating gas, that from three other seams about two thirds as much, while that from others is much less. The two analyses for XIV. and for XVI. are from different localities, but only a short distance apart. The local conditions

differ little but the oxygen-content at Szabolcs is very much greater than at Colonie. The proportion of oxygen has apparently no relation to the depth below the surface.

The analyses by Nendtwich[47] show as a rule less ash in the Steierdorf coals than in those of Fünfkirchen but the oxygen is somewhat less.

The Lower Jurassic coals of Siberia, according to analyses given by the Comité géologique, show extreme contrasts. I. and II. are from the Tchoulym field and III. is from the Grande-Bira area.

	Water.	Ash.	Carbon.	Hydrogen.	Oxygen.
I.	11.68	1.56	69.92	6.13	23.95
II.	16.66	2.28	69.73	7.12	23.15
III.	2.35	12.00	81.8	5.5	12.7

The brown coal obtained in other districts is much inferior, as ash is very high.

The Jura-Trias coals of Queensland are bituminous throughout. Jack reports only proximate analyses but these suffice to show the great difference in conditions:

IPSWICH GROUP.

	Water.	Ash.	Volatile.	Fixed Carbon.
I	1.00	24.35	32.42	67.57
II		19.00	27.7	72.2
III	1.32	31.61	29.3	70.6
IV	2.02	22.8	30.8	69.1
V	1.32	19.70	29.3	70.6
VI	8.10	2.50	43.29	56.70
VII		16.00	42.81	57.1

BURRUM GROUP.

	Water.	Ash.	Volatile.	Fixed Carbon.
I	2.50	2.50	32.00	68.00
II	2.00	8.00	31.25	68.75
III	2.25	2.10	30.47	69.53
IV	2.75	3.25	29.50	70.50

The Ipswich coals throughout are very high in ash, the specimen VI. being picked from a thin band; all the coals except VI. and

[47] C. M. Nendtwich, "Ungarns Steinkohlen, etc.," *Haidinger's Berichten*, Band IV., 1848, pp. 18, 21, 30.

VII. are coking; the high volatile in these last, so greatly beyond that of other coals within the same little area, suggests that perhaps they contain some cannel. The Burrum specimens are all from a very small area, where mining has been carried on extensively and they are from only two seams. II. and III. are from the bottom and top of the Lapham or most important seam. The ash is low throughout, showing that, in this area at least, the conditions were favorable to the accumulation of clean coal. All of the seams yield good caking coal, though they differ in the hardness; that from several seams is hard shipping coal whereas that from others, especially that from one, is tender and therefore inferior as a steam coal. There is nothing in the structure to explain this difference as the seams are separated by a small interval. The Lapham coal yields 10,200 cubic feet of gas per ton, with 14.73 candle power; this is the result of a trial lasting for 20 months.

The Triassic coal of Norroy, France, was analyzed by Regnault, who obtained 19.20 per cent. of ash. The ultimate composition of the pure coal is: Carbon, 77.23, hydrogen, 5.39, oxygen and nitrogen, 17.37. Servier asserts that the specimen was not fairly representative and gives the results of a proximate analysis by himself: Moisture, 10.00, ash, 9.20, volatile, 42.4, fixed carbon, 57.5. This he regards as a fair average composition. He thinks it is a transition from brown to stone coal but the distillate is alkaline, not acid.

The Upper Triassic coals of the Richmond basin are all of high-grade bituminous quality, are caking and for many years they were used in the manufacture of illuminating gas in New York, Philadelphia and other large cities. The available analyses are those reported by W. B. Rogers,[48] which represent the average of the coal as observed at the more important localities. Twenty-two analyses were made. The ash is below 6 per cent. in all except 7 and exceeds 11 per cent. in only 3. The volatile in pure coal varies from 30 to 40 per cent., south from James River, and from 25 to 35 in mines north from that river. Much of the basin is broken by dikes which in some portions have converted the coal into coke; but there are anomalies not due to the influence of igneous rock. Analyses of samples from the bottom, middle and top of the thick

[48] W. B. Rogers, "Report of Progress for 1840," reprints, pp. 532–535.

mass in one shaft show 40, 30 and 31.7 per cent. of volatile in the pure coal, with 10.82, 5.10 and 9.52 of ash. In a shaft, north from James River, the 4 divisions of the coal show a difference of about 4 per cent. in volatile, while the ash is 5.20, 22.20, 9.80 and 22.60 in the several divisions.

Stone, in his report already cited, has given analyses of the coal at Leakesville in the Dan River area of North Carolina. The seam is an insignificant lens but is apparently the most important deposit in that area. It is in two benches separated by only 2 feet of micaceous shale but the composition is very different. The

	Water.	Ash.	Volatile.	Fixed Carbon.
Upper bench..............	11.67	9.65	38.6	61.3
Lower bench..............	5.35	20.27	12.8	87.1

lower bench is anthracitic and the upper bench is a high-grade bituminous. The sulphur in both is at most little more than a half of one per cent. The ash is very much higher at most of the North Carolina localities, occasionally reaching 39 per cent. in "best coal."

It may be well to gather the notes respecting ash as presented in the several analyses. The conclusions at best can be merely tentative because analyses, in almost all cases, appear to have been those of hand specimens supposed to represent the average of the seam as shipped: and there are comparatively few showing the composition of coals not regarded as fit for working. It is sufficiently clear that conditions were not the same in all portions of the area occupied by any seam or during the time of its accumulation.

In the Jurassic region of Austria, the coal of one seam near Bernreuth, though externally resembling good coal, has 42 per cent.; near Gresten, the same seam has only 3.9 per cent. The ash is low at Hinterholtz but at Grossau it rises to 10 per cent. At Pechgraben the average of all analyses is 17. These in all cases are from coals which are mined. No attention was paid to other seams because they are "dirty." Similar conditions exist in the Triassic region of Austria. Near Kleinzell, the highest seam has 14 per cent.; near Lilienfeld, the good coal, with little more than 7 of ash, is in the middle seam; near Kirchberg, the coal mined has from

15.8 to 19.9 of ash; but near Rehgarten, the same beds yield a coal, with only 7.8 per cent. of ash; at Loichgraben, the lower seam has good coal, while that from the upper seam, though in appearance equally good, has 52 per cent. Coal is mined near Gossburg, which contains upwards of 30 per cent. of ash. Rachoy has shown clearly that in both Jura and Trias a seam varies greatly in this respect in different portions of its area.

There are numerous coal seams in the Steierdorf-Anina area of Hungary, but only 5 of them are workable—each of these in limited spaces. They are divided into benches, some containing good coal, the others worthless. Samples of good coal from the highest two have from 1.28 to 7.26 of ash, while those from the third have from 2.56 to 16.78. The fourth seam shows less variation, the percentage being 3.44 to 5.65. Within the Fünfkirchen region, 174 seams were crossed by the tunnel at Vasas, with a total thickness of 52 meters. Thirty-nine of them, 14 meters thick, are "dirty" and worthless; of the 28 seams, which are workable in areas, large or small, at least one third become at times too impure to be mined. Hantken gives 26 analyses; 5 show between 16 and 20; 7, from 12 to 15; 4, from 10 to 12 and only 5 have less than 6 per cent. of ash. All of these are from mines in full operation.

The brown coal of the Tchoulym field in Siberia has at most only 2.28 of ash in the samples analyzed but, apparently, the same horizons in the North Tchoulym area yield coal with more than 30 per cent.

The Ipswich seams of Queensland have from 19 to 31 per cent. of ash, while the Burrum coals are all remarkably free from mineral matter, the highest percentage being only 8.

The analyses of specimens from the two benches of a coal seam in the Dan River district of North Carolina show 9.65 in the upper bench and 20.27 in the lower. The best coal in the area has only 5 to 6 per cent., but other samples of "best coal" contain from 20 to 39 per cent. Samples taken by the early students in the Richmond basin were all from the mines then in operation. The lower division of the great seam is usually described as much inferior to the higher portions. In most cases, the samples appear to have been chosen from the better portions, for the ash rarely exceeds

5 per cent.; but in two mines the samples represent different parts of the great seam and the contrast in conditions is marked; at one mine, the ash content in the several parts is, ascending, 10.82, 5.10 and 9.52; in another, the percentages are 5.20, 22.20, 9.80 and 22.60.

There is little of detailed information respecting variations of coal in different portions of lenses, as analyses have been made only of coals supposed to be worth mining. But incidental references abound, which show that, toward the borders, ash increases until the coal becomes worthless.

Summary.

The areas of Jura and Trias, containing coal in economic quantity, are utterly insignificant, when compared with those in which the systems are exposed; but there are many localities in which coal accumulated during brief periods and amid unfavorable conditions. The oölite coals of Britain and a few spots on the continent of Europe are of inferior quality, merely local and almost without interest. Elsewhere the useful deposits are in the lower part of the Lias and in the highest divisions of the Trias. The Jurassic above the Lias and the Triassic below the Keuper may be regarded as barren.

The associated rocks are as in the later periods. The Oölite coals of England are intercalated in sands; the Jurassic coal of Spitzbergen is confined to the Middle or sandstone division, as defined by Nathorst; the Grestener or coal-bearing Lias of Austria is composed of sandstones and clays; the same conditions prevail in the Liassic coal areas of Hungary and Siberia; the Jura-Trias of Queensland and New South Wales are almost wholly sandstone; the upper Trias in Austria and Hungary is sandstone with intercalated shale. But the Jura in Alaska is almost wholly shale and the Upper Trias in some small areas has little sandstone. Freshwater fossils, in rocks associated with coal seams, have been oberved in England, Siberia, Spitzbergen, France and Quuensland. The structure of the rocks is evidence of, at most, shallow water and in some cases it is very suggestive of eolian agency. False bedding is reported from England, Australia, Germany and North Carolina and ripple marks

are common features at many places. Sandstones and shales frequently contain logs of wood, in such relations as to leave little room for doubt that they are simply stranded material.

There is, however, ample proof that the sea invaded many places where coal was accumulating. The Lower Oölite of England has beds with great abundance of fragmentary marine shells; the Liassic sandstone of Austria and Hungary includes layers with many marine mollusks of littoral types; *Ammonites* was found at one locality, but that does not militate against the conclusion that the water was shallow—if the shell be not drifted, it shows that the genus could exist in shallow water; the Rhætic of Sweden is freshwater below, but has marine shells in the upper portion, where the coal seams are very thin and impure. The lower beds of the Jura-Trias in Queensland have yielded a few specimens of offshore mollusks. The incidental references to beds with marine fossils do not enable one to determine the extent of areas covered at one time or another by salt or brackish water; but in the Fünfkirchen district of Hungary such beds, though few in number, are present in the roof, floor or even partings of several coal seams, recalling the conditions observed in southwestern Utah, within the Benton, near base of the Upper Cretaceous, where a coal seam between beds of marine limestone has freshwater mollusks in a parting. In any event, these deposits suggest that the areas in which they exist were lowland, close to the ocean level. The shallowness of the water cover during their deposition is so evident that one may well conceive that the invasions were due to diversions of drainage, to shifting of channels of large streams. How readily such shifting of channel ways may change conditions in a plain country is shown by Featherstonhaugh's[40] statement that, in one area, the Arkansas River broke through its banks and converted 30,000 acres into swamp land, killing all the trees. Still more remarkable illustrations exist on the broad plains bordering the Paraguay and other rivers in South America. Many times in sections of coal-bearing rocks, marine deposits are in contact with those of land origin or are separated from them by an inch or two of fine sediment.

[40] G. W. Featherstonhaugh, "Geological Report of Examination of the Elevated Country between Missouri and Red Rivers," Washington, 1835, p. 84.

The lenticular form of coal seams is as distinct in the Jura and Trias as it is in later periods. It is characteristic of Jurassic coals in Great Britain, France, Austria, Hungary, Siberia and Queensland, as well as of Triassic coals in France, Austria and the United States. Direct reference to this feature is not made in some of the earlier reports as, at the time the studies were made, the bearing which the form of coal seams has upon the problem of their origin was not recognized. But in every area the varying thickness of coal seams is emphasized; the frequent passage of coal into carbonaceous shale is noted; the presence of coal seams in some vertical sections and their absence from others attracted the attention of all observers. The lenses may have considerable area but often they are small; they may be thick or thin. Those of the Tchoulym field of Siberia have small superficial extent, rarely exceeding a few square kilometers and they are rarely connected, but their thickness is so great that the Russian geologists speak of the total quantity of coal in this district as "colossal."

References to contemporary erosion are rare in the reports. Wilkinson has recorded instances of filled channel ways in the Triassic of New South Wales and Hertle has described an interesting "horseback" in a Triassic seam near Rehgarten in Austria. The irregularities in the roof of coal seams in the Richmond field, as described by several observers, have much resemblance to "horsebacks," but the mines in which they were seen were abandoned half a century ago, so that one cannot determine whether or not these irregularities are due to trenching of the coal seams.

Soils of vegetation have been reported from England and the United States, but, if they be present elsewhere as one should think probable, observers have failed to make note of them. In such soils one finds vertical stems of plants, rooted apparently in place of growth but not associated with seams of coal. The Purbeck "dirt beds" of southern England have stumps of conifers and cycads rooted in carbonaceous clay. Mantell states that the conifer stems have lost their bark and have a weatherbeaten surface like that of posts set between tides. They resemble the stumps exposed above the Yahtse gravels, as described by Russell. Stems of the Purbeck conifers were snapped off at 3 or 4 feet from the ground

and they lie prostrate in intervals between the rooted stumps. Henslow saw, at the Portland locality, root-shaped cavities descending into the rock underlying the dirt bed. Equisetiform plants in vertical position and rooted in place of growth occur at several horizons in the Lower Oölite and the Lias in Yorkshire. *Calamites* and *Equisetum*, in erect position, are found in beds above and below seams of coal at numerous localities within the Richmond field. These ancient soils, with erect stems in place, would seem to indicate land surfaces at various times during deposition of the coal-bearing deposits.

As in the newer formations, the roof may be sandstone, shale or limestone; it may contain marine or freshwater forms. At Brora in Scotland, it is a mass of marine shells with quartz sand and carbonaceous materials, bound together by a calcareous cement; it passes downward into coarse coal—a faux-toit. Marine shells are present in the roof of at least one seam in the Fünfkirchen district and bituminous limestone rests on the coal at some localities near St. Anton in Austria. The ordinary roof is sandstone or shale, one or the other predominating in different areas; not infrequently it is sandstone in one mine but shale in another nearby. Finely laminated sandstone is not rare. Roof shales are often very rich in plant remains, leaves being especially well-preserved, as though they had been lifted gently from the surface of the bog by muddy water. The sandstone roof of the Lettenkohle in Unterfranken is an old soil, containing erect roots.

Frequently, the passage from good coal to roof is gradual and this is equally true of the passage from coal to the floor, there being distinct faux-toit and faux-mur; but, at times, the passage is abrupt. Occasionally, the character of the coal changes in such manner as to suggest that one portion of the seam sank below drainage while the other remained above it; the "Kimmeridge coal" in the typical area is merely a rich carbonaceous shale, whereas in Wiltshire it resembles peat. In the Tchoulym field of Russia, the burial must have been abrupt, for the upper portion of the coal is very peat-like at some localities. Coal seams, more than 2 feet thick, are rarely single, but are divided into benches by partings of sandstone or clay, often containing much mineral charcoal. These vary much

in thickness. The interval between seams XI. and XII. in the Fünfkirchen area is from zero to 72 feet; similar, though less marked variations are recorded from other localities. Ordinarily, the partings appear to be of freshwater origin, but occasionally one contains marine forms of immediately offshore types. The character of the coal differs greatly, many times, in the several benches; some yield excellent coal, but that from others is worthless; that from one bench may be caking, that from another may be non-caking; that from one bench may be richly bituminous while that from another may be almost anthracitic. Coal of Jurassic and Triassic age is usually so far advanced in chemical change that identifiable plant structure seldom appears in the coal itself until after treatment with Schultze's solution. But Grand'Eury states that, at Nice, *Equisetites* is present in the coal, recognized by its form, though all trace of structure had disappeared. The Keuper coals of the Vosges contain bark and seeds, while Rhætic coal from Bayreuth has many streaks which appear to consist wholly of pollen exines. In the Rhætic of the Richmond field *Equisetum* is abundant in coarse coal. But treatment with Schultze's solution brings out evidence of vegetable tissue from all the coals examined.

The floor is as variable as the roof, being clay, shale or sandstone. Limestone is reported from only two localities described in works consulted by the writer. Within several counties of England the floor of the Lower Oölite coal or coaly shale is usually clay or fine-grained more or less clayey sandstone and it contains many roots, which, in at least one locality, clearly descend from the overlying coaly shale. A calcareous floor in the Causses of France holds roots, which are well defined. Lipold and his associates give no details respecting the floors of Austrian coal seams but the presence of plant remains is recorded incidentally for many localities. The presence of roots in floors is a familiar phenomenon in the Lias of Hungary; in the Steierdorf-Anina district, they are described as vertical, often branching, and they are associated with plants of several types. According to Grand'Eury, roots, both woody and herbaceous, are abundant in underclays and partings. The condition is similar in the Fünfkirchen area, where, according to Gothan, the underclay proved to be a root-bed in every locality

at which the floor could be studied. *Vertebraria* has been recognized in underclays of Queensland; *Equisetites* roots are in underclays of the Vosges as also at Nice, where the plants seem to have supplied material for the coal. The underclays of Lettenkohle in Unterfranken are root-beds. The coals of the Richmond field, according to Rogers, have nothing answering to the *Stigmaria*-clays of the Carboniferous; but the underclays are present. They carry no *Stigmaria,* for the gigantic *Lepidodendron* and *Sigillaria* had disappeared; but Fontaine has shown that *Schizoneura* is present in the floor of the main bed.

The flora has been studied in all of the important areas. In the Upper Oölite of southern England, ferns, conifers and cycads are the prevailing types; the Lower Oölite of Yorkshire contains ferns as the preëminent feature though conifers and cycads are abundant; *Equisetum* is common above the coal horizon, at which ferns and conifers prevail. Conifers, cycads and some ferns from Spitzbergen have been described by Nathorst. The Ipswich or upper division of the Queensland Jura-Trias has 11 species of ferns, 4 of cycads and one of *Equisetum;* ferns prevail in the lower portion of the Lias within the Steierdorf-Anina area and cycads in the upper; but in the Fünfkirchen area, the flora consists chiefly of ferns, cycads and lycopods. *Equisetum* is extremely abundant in the Trias of Austria and *Calamites* and *Pterophyllum* were obtained at many places; the Trias of Hungary has yielded cycads, *Palissya* and some ferns, but collections have been small, as the coal is unimportant. The beds in the Atlantic coast areas of the United States contain cycads, reeds and ferns—the last being few in species but extremely abundant in individuals.

That the coal-bearing deposits were laid down on an undulating surface is well shown in the Liassic areas of Hungary. Within the Törzburg area, the underlying rock is crystalline schist; in the Steierdorf area it is Dyas but in that of Fünfkirchen it is Trias. A similar condition is distinct in the Trias of Virginia and North Carolina. In the Richmond field, the interval between the lowest coal seam and the granite varies from a few inches to 600 feet, while in the Dan River basin of North Carolina it is more than 1,000 feet.

INTERRELATIONS OF THE FOSSIL FUELS.*

IV.

By JOHN J. STEVENSON.

(*Read March 5, 1920.*)

The Paleozoic Coals.

In a great part of the areas, where deposits of Permo-Carboniferous age are exposed, the passage from Triassic is gradual; at most, the plane of contact shows only petty discordance of stratification. But in many extensive areas, the succession is incomplete and one or more members are missing, so that the Triassic may rest on any formation from Archean to Permian. In like manner, where the succession is complete, the Permian may pass downward into the distinctly Carboniferous so gradually that no definite boundary can be determined stratigraphically or by aid of changes in plant or animal life. At times, deposits assigned to the Permian rest on pre-Carboniferous rocks; at others, there is distinct discordance between Permian and Carboniferous, while in vast areas the succession is apparently conformable throughout. Lithological changes usually occur in the upper part of the section; at one time, the presence of red rocks was considered proof that Permian had been reached. This opinion is not final, in many regions red beds occur in distinctly Carboniferous deposits. Frequently, the basal portion of the Permian contains conglomerates, holding pebbles, striated seemingly by glacial action.

The problem of the relations between Permian and Carboniferous coal measures is vexatious to the last degree, as the testimony of stratigraphy, paleontology and paleobotany seems to be in conflict. In some cases, the conflict is not real, but in others it is a

* Part 1 appeared in these *Proceedings*, Vol. LV., pp. 21–203; Part II. in Vol. LVI., pp. 53–151; Part III. in Vol. LVII., pp. 1–48.

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fact and it can be removed only by revision of conceptions, which have become laws, because accepted for a long time. But questions of nomenclature and relations have only incidental importance in connection with matters under consideration in this work. The term Permo-Carboniferous will be employed here, as it has been accepted by many students; it renders unnecessary all discussion as to propriety of regarding the Permian as more than a subordinate division of the Carboniferous.

PERMO-CARBONIFEROUS COALS.

Australia.

Queensland.—Jack and Etheridge[1] include under the name Permo-Carboniferous, the rocks between Devonian and Trias-Jura and divide them into the Star, Gympic and Bowen formations.

The Star and Gympic yield a flora of distinctly Carboniferous type; the fauna is marine and certainly allied to that of the Lower Carboniferous. The relations of these formations to each other were not determined, as they occur in isolated areas; they have *Calamites, Lepidodendron, Cordaites* and eleven genera of invertebrates in common, but a number of species are peculiar to the Star. *Lepidodendron* abounds in sandstones and some shales. The Gympic beds are much disturbed, those of the Star, very little.

The Bowen, divided by Jack into Lower, Middle and Upper, had not been found in contact with the Lower Carboniferous up to the time when the report was prepared. Lycopodiaceous plants are wanting, their place being taken, apparently, by the fern *Glossopteris.* The Lower Bowen has yielded no remains of animals and it is capped by a series of bedded volcanic rocks; the Middle is rich in mostly marine mollusks and contains some remains of land plants; The Upper had abundance of land plants and one bed has marine mollusks like those of the Middle. The Bowen is thought by Jack to be equivalent to the upper portion of the New South Wales Permo-Carboniferous.

The Lower Bowen, consisting of grits, sandstones, conglomerates

[1] R. L. Jack and R. Etheridge, Jr., "The Geology and Palæontology of Queensland, etc.," Brisbane, 1892, pp. 3, 70, 135, 141, 147–159, 161–171.

and shales, contains remains of reed-like plants with fragments of silicified wood in the sandstones and shales; black shale with highly carbonaceous bands was seen at one locality, but no coal was discovered anywhere. The Middle or marine Bowen, composed of yellow to gray sandstone, with blue to yellow-gray shales and some ferruginous bands, is remarkably rich in mollusks, some of which belong to Permian types. Vertical rootlets in shales and sandstones are taken by Jack to indicate occasional recurrence of land surfaces. Silicified trunks of trees, prostrate, were seen in sandstone at several localities. Only two coal seams were recognized; the Kennedy, of merely local importance, is about 2 feet thick, double or triple, and rests on a floor containing vertical rootlets; the Garrick, higher in the formation, and 4 feet 9 inches thick, shows near the bottom a light lustrous coal in nodules of 3 to 4 inches diameter. The coal in the main portion of the seam yields a bright, hard coke but coke from the nodules is spongy. The floor is soft sandstone and contains rootlets; the prevailing plants are *Sphenopteris* and *Glossopteris*. The Upper Bowen, including many sheets and dikes of diorite, consists of gray shales and greenish-gray sandstones with some conglomerate. The Daintree coal seam, near base of the formation, is exposed in the bed of Bowen River, where it is less than 10 feet below a mass of diorite. The section is (1) Burnt coal, partly columnar, contains *Glossopteris,* 3 feet 7 inches; (2) black shale, 1 inch; (3) burnt coal, 3 inches; (4) stony burnt coal with silky plant débris, 6 inches; (5) light, porous, crumbling coal, with concretionary nodules of better coal, 8 inches; (6) blue-black shale, 2 feet 3 inches; (7) light brownish-black, laminated coal, with laminae of oil-shale, 7 feet; (8) blue-black shale, 2 feet 3 inches; (9) good coal, 3 inches; total, 17 feet 5 inches. The influence of the diorite sheet disappears at about 15 feet. The McArthur seam, higher in the section, is in 5 benches with a total thickness of 12 feet 3 inches, but the coal is only 5 feet and has 32 per cent. of ash. The sandstones above this coal contain large stems of drifted coniferous trees, which are silicified and, at times, retain some of their roots. A third seam, unimportant, is near the top of the formation and only a few feet below red sandstone with a marine fauna.

The Bowen coals are inferior; thos of the Middle have from 11

to almost 17 per cent. of ash, while those from the Upper have from 14 to 38. Great variation occurs in a single seam; anthracite at one place, 4 feet 4 inches thick, has at one mine only 3.5 per cent. of ash, whereas in another it has 23.61. No igneous rocks were seen in the neighborhood.

New South Wales.—The Permo-Carboniferous, according to David,[2] is divisible within the Hunter River region into

The Newcastle Series, freshwater, with coal seams	1,400 to 1,500 feet
The Dempsey Series, freshwater, no workable coal	200 to 2,000 feet
The Tomago Series, with coal seams	1,600 to 1,800 feet
The Upper Marine Series, without coal	5,000 to 6,400 feet
The Greta Series, with coal seams	150 to 300 feet
The Lower Marine Series, with little coal	4,800 feet

A great gap exists between Carboniferous or "Gympic" deposits, which, most probably, belong to the Lower Carboniferous. On the border of Queensland, in the Ashland coal field, the Permo-Carboniferous rests in great unconformity against the Lower Carboniferous, which is not far from 20,000 feet thick. This vast mass consists, in the lower and middle divisions, of marine beds, but the upper division is mostly lava and volcanic tuffs. The gap is indicated not only by the angular unconformity but also by the fact that but one genus of plants is common and the contrast in fauna is almost as great.

The Lower Marine Series has, at base, a deposit about 200 feet thick, underlying a basalt sheet and containing many glaciated pebbles. The first appearance of *Gangamopteris* is at about 3,000 feet from the base; and at 500 feet higher is a coal seam of rather inferior quality, 10 feet 6 inches thick, inclusive of the partings which contain *Gangamopteris*. The Greta Series, sandstones and shale, has near the base the Homeville seam, 3 to 11 feet 6 inches thick, hard, bituminous coal; at the South Greta mine it rests on Kerosene shale. At 50 feet higher, the interval being filled with sandstone, conglomerate and shale, is the Greta seam, 14 to 32 feet thick, with floor of shale and roof of sandstone or conglomerate. Where the

[2] T. W. E. David, "The Geology of the Hunter River Coal Measures, New South Wales," *Mem. Geol. Survey of New South Wales*, No. 4, 1907, pp. 311–327, 354.

roof is sandstone, marine fossils are present at a little way above the coal. Locally, owing to increase of the alga, *Reinschia australis,* it passes over to cannel or even to Kerosene shale. The coal seams of this series divide toward the north, which David takes to be wholly normal; the Carboniferous had been elevated to form highlands on that side, so that the quantity of transported material increased in that direction. The Tomago Series, sandstones, conglomerates and coal seams with beds of iron ore, has six workable seams, which yield excellent coal but too friable for shipment, being inferior in that respect to coal from the Greta and Newcastle. The Newcastle Series has many coal seams of high grade and great persistence. This series is notable because of abounding *Vertebraria* in the floor and of *in situ* tree-stems in the roof of coal seams.

Wilkinson,[3] many years ago, separated the deposits into Upper and Lower Carboniferous. The latter has marine fossils in many beds, while in others *Lepidodendron, Sigillaria* and *Calamites* abound, but workable coal seams are unknown. This is equivalent to the Lower Marine Series of the Hunter River field. The Upper Carboniferous has, below, the important seams at Greta and East Maitland, separating the two Marine Series. The plants are species of *Glossopteris, Phyllotheca, Noeggerathia* and *Annularia. Phyllotheca* and *Glossopteris* occur on slabs, associated with characteristic fossils, which McCoy, de Konninck and others have recognized as Carboniferous. The Upper Carboniferous had been referred to the Permian, but Wilkinson accepted this as only a provisional reference. The characteristic plants are *Glossopteris, Gangamopteris, Vertebraria, Phyllotheca* and *Sphenopteris,* but marine shells appear to be wanting. This upper division is evidently equivalent to David's Tomago, Dempsey and Newcastle. The *Glossopteris* of New South Wales is of interest because of the memorable controversy between McCoy and Clarke,[4] in which the former maintained that the presence of this plant proved Mesozoic age for the deposits, because in India it occurs in Oolitic rocks, whereas the

[3] C. S. Wilkinson, "Notes on the Geology of New South Wales," Sydney, 1882, pp. 44, 45, 51.

[4] W. B. Clarke, "Remarks on the Sedimentary Formations of New South Wales," in Mines and Min. Statistics of New South Wales, 1875, contains a history of this dispute, pp. 161 et seq.

former asserted that the fauna was absolute proof of Paleozoic age. It may be well to recall that this fauna reappears in Queensland at top of the Bowen formation.

According to Mackenzie,[5] the coal seams of the upper measures are much broken by partings, usually thin. The seams, at times, are thick, 8 to 26 feet, but much of the coal is poor. A faux-toit, consisting of coarse coal and "coal and bands," 4 to 12 feet thick, is present at many localities. The benches frequently differ in character of the coal. The roof and floor are usually shaly clay and in most cases the roof is plant-bearing. The coal seams of the lower coal group are much divided and show great difference in the several benches. Occasionally the underclay is crowded with *Vertebraria.*

The lens shape of coal seams is a by no means rare feature. The important seam at Greta suffices for illustration.[6] At the Greta mine, it has 6 benches, including one of Kerosene shale, and is 26 feet thick, inclusive of 6 feet of partings and inferior coal; but within 32 chains it becomes only 17 feet 6 inches, while at three miles north it is but 7 feet 6 inches and the Kerosene shale is wanting. That shale occurs as lenticular deposits with the seams, and bears close resemblance to cannel in mode of occurrence. Liversidge[7] states that at Joadja Creek this mineral contains *Glossopteris* and *Vertebraria.* The fronds of the former usually are spread between the laminæ but the latter crosses them.

David[8] says that the Stony Creek and Greta coal measures, underlying the Upper Marine Series, are thin at the south but become thicker northward, the increase being due to splitting of an important coal seam into several thinner ones. At East Maitland, he saw in the East Maitland (Tomago) series a coal seam, consisting of an upper division, clays and coal, 4 feet, and a lower division, coal and thin partings, 4 feet. At little way northward, the divisions have become distinctly separate seams and, at another locality farther north, the interval between them is 140 feet. In a later report, he

[5] J. Mackenzie, "Mines and Mineral Statistics," pp. 209–243.

[6] Annual Rep. Department of Mines, 1883, p. 149.

[7] A Liversidge, "Description of the Minerals of New South Wales," Sydney, 1882, p. 160.

[8] T. W. E. David, Ann. Rept. Dept. of Mines for 1887, pp. 147, 149, 151; the same for 1890, p. 229.

notes his discovery of *Glossopteris* leaves in closely matted layers within a soft fireclay. They were undecomposed, were not brittle or carbonized, but retained the original substance. Soaked in glycerine and water, they could be unrolled and laid out flat. A large number of the specimens were mounted and placed on exhibition in the Museum of the Department of Mines.

More than forty years ago, Wilkinson stated that "on the coast, near the Nobby, Newcastle, may be seen several trunks of trees up to one foot thick, with roots attached, starting from a seam of coal and embedded in the strata in the upright position in which they grew." In the interval since Wilkinson studied the region, detailed examinations have been made and the conditions have been presented by David[9] in his remarkable memoir on the Hunter River. It will suffice here to cite only the description of features observed in the Newcastle or highest Series. That contains 12 seams, which are workable in more or less extensive areas and occur in two divisions, separated by a thick deposit containing much diagonally-bedded conglomerate in great lenses. The color of this mass is greenish- to reddish-brown.

The Wallarat or Bulli seam, at top of the Permo-Carboniferous, directly underlies the Trias and is much eroded; its underclay is a root-bed. The Great Northern seam, 14 feet thick and 120 feet lower, underlies conglomerate and is much eroded at the junction. The conglomerate, at base, holds flattened stems of trees. At the cliffs of Catherine Hill Bay, the top of this seam has numerous stumps of large trees and the underclay has vertical *Vertebraria*, separated by intervals of about 2 feet Below the floor of this coal seam is the Fennel Bay fossil forest, which is persistent in the Newcastle Series at 20 to 80 and 100 feet below the Great Northern. These plants are *in situ*. At somewhat more than 200 feet below the Great Northern the lower Pilot seam is reached, 5 feet thick and 33 feet below the upper Pilot, the interval being filled with tufaceous beds. The top portion of the lower seam, splint coal, has great numbers of vertical trunks and stumps, rooted in the coal, in some cases 30 feet high, reaching to the floor of the upper bed.

[9] T. W. E. David, "Geology of the Hunter River Coal Measures," pp. 3–41, 330–332.

This upper bench of the lower Pilot is a network of long straight roots radiating from the stumps. David recognizes that the tuffs must have accumulated rapidly as, otherwise, the stems would have rotted away. This roof forest is well shown on French Bay of Lake Macquarie. The tree stems are chalcedony above the coal, but in the coal they are a hydrocarbon. They are 10 to 15 inches thick and are about 5 yards apart. Drops of resinous matter, distilled from the broken branches, are present in tuff surrounding the stems, such as one finds in recent tuffs within the Andes region. The lower bench of the bed has numerous stems and vertical roots, which David conceives may be the remains of another fossil forest. The under clays of both Pilot seams have abundant *Vertebraria,* while some partings have *Vertebraria* and *Sporangia.*

The Burwood seam, 13 feet thick inclusive of partings, gives evidence of contemporaneous erosion before or during deposition of the overlying shale. The conglomerate above has rounded pebbles of coal, one to three inches diameter. David is inclined to believe that these came from the Burwood seam, though he grants that the source may have been one of the Greta seams. They are proof that when the conglomerate was deposited coal, already hard, existed. *Vertebraria* abounds in underclays of coals in the lower division and stumps, *in situ,* were seen in the roof of several seams. A gravel bank, 70 feet thick and one fourth to one half mile wide, marks the course of an ancient erosion. The vertical stems, in all cases, are conifers.

In summing up the facts, David state that the floor of each seam contains abundance of *Vertebraria* (the root of *Glossopteris*), while the roof shows more or less well preserved stumps of *in situ* trees. The lower part of stumps and roots, where they form part of the coal seam, still retain a large proportion of the original carbon and only the upper part has become slightly silicified. But the tree stump, where extending a few feet above the coal seam, is completely silicified, changed into chalcedony, but the minute tissue is usually preserved. Where the woody portions are replaced with carbonate of iron, retaining the woody structure, the bark, one or two inches thick, has become brittle, bright bituminous coal. This leads him to suggest that the bright laminæ of the coal were made

from bark of coniferous trees and that the dull, splinty laminæ, containing a notable proportion of mineral charcoal, were derived from *Glossopteris* stems and leaves. Sporangia abound but not in quantity to give spore coal.

The prevalence of *Vertebraria* makes probable that the peaty swamps, now represented by the coal seams, began as fern brakes with reeds. He had never seen a tree stump in the underclay. The swamps at length became Waldmoors, covered with Dadoxylon forests. These, at several horizons, were overwhelmed by showers of volcanic dust and drops of resin were preserved in considerable quantity within this dust.

Cannel occurs as lenses within the thick Greta seam; the oil shale or Hartley mineral occurs in like manner as lenses within the coal, These, at times, are of considerable lateral extent and occasionally that mineral forms a more or less persistent bench, in which the richness varies greatly. The character of coal is rarely the same throughout a seam, cannel, splint and bright bituminous being found frequently in the section of a single seam.

India.

The Permo-Carboniferous of India is exposed in isolated fields, large or small, within a strip, crossing Hindostan between parallels 19 and 24. These deposits, belonging to the Lower Gondwana, are divided into the Panchet, Raniganj, Barakar and Talchir, of which Panchet has been referred to the Trias. The Raniganj and Barakar are equivalent to the Upper and Lower Damuda and, in much of the region, are separated by a mass of clayey to sandy and carbonaceous shale, holding much clay iron stone. Coal is confined practically to the Damuda beds, there being only occasional carbonaceous shale and local seams in the Talchir. This lowest member consists of greenish, at times sandy or gravelly muds, frequently containing pebbles and large blocks of rock, so that, in places, there is a distinct bowlder bed. The variations of the Permo-Carboniferous can be made clear by examination of several fields from east to west.

The *Rajmahal* fields is northeast from Calcutta between the

Ganges and Dwarka Rivers. Ball[10] reports that the Talchir has no coal but has *Gangamopteris*. The Barakar, in the northern part of the area, consists of coarse, friable, feldspathic grits with white argillaceous shales and a few seams of inferior coal. False-bedded sandstones occur near the coals.

The *Jheria* field[11] is on the northerly side of the Damuda River and its easterly boundary is about 170 miles above Calcutta in Bengal. The Damuda and Talchir are not far from 6,800 feet thick. The Raniganj, largely sandstone, seems to be without coal, and the same condition marks the Talchir. Some carbonaceous shale in the latter has ill-preserved remains of plants, among which is a form closely allied to *Glossopteris*. The Barakar, consisting of clayey, sandy or carbonaceous shales and shaly sandstones, with grits and sandstones in the basal portion, has coal seams in all portions; but these are thickest in the coarse lower part. At all horizons, these are variable in thickness of coal and of partings; pyrite is abundant and the quantity of mineral matter renders the coal almost worthless.

On the Chat Kurree Jour, some seams are very thick; Hughes noted thicknesses of 50, 6, 5, 8, 13 feet. The thickest deposit is at the base and is a mass of shale and bad coal; but there is one seam, almost 5 feet thick, which is fairly good bituminous coal with only 11 per cent. of ash. Concretionary nodules were seen at several localities; the laminæ of the enclosing coal cross the concentric laminæ; the nodular coal is better than the enclosing material. The characteristic plants are *Glossopteris* and *Vertebraria*; no marine fossils were observed but there are freshwater limestones with *Melania, Paludina* and *Planorbis*. The seams are extremely irregular and appear to be of limited horizontal extent. Hughes is confident that the absence in so many places cannot be due to faulting and that the only explanation is that they are merely local deposits.

The *Raniganj* field is west from the Jheria and 120 to 160 miles northwest from Calcutta. There Blanford[12] found the Talchir rest-

[10] V. Ball, "Geology of the Rajmahal Hills," Mem. Geol. Survey of India, Vol. XIII, 1877, pp. 155–248.

[11] T. Hughes, "The Jheria Coal-Field," Memoirs, Vol. V.,. 1866, pp. 227–236.

[12] W. T. Blanford, "On the Geological Structure and Relations of the Raniganj Coal-Fields," *Memoirs*, Vol. III., 1865, pp. 1–195.

ing on gneiss. It has a bowlder bed on top and its shales and sandstone often have rippled surfaces as well as obscure impressions, suggestive of footprints. No coal was seen and the plants, which are not abundant, belong mostly to *Glossopteris* and *Cyclopteris*. The Lower Damuda (Barakar) has coarse to conglomeratic white sandstone at base, succeeded by coarse, micaceous shaly sandstone with seams of coal and shale, often thick. "These seams are irregular both in thickness and in quality; they frequently disappear entirely or pass into shale or even sandstone within short distances." The Lower Damuda is about 2,000 feet thick, a notable decrease from the Jheria field, where it is about 3,300. The ironstone group, overlying the Lower Damuda, is about 1,200 feet thick and contains no coal. The Upper Damuda (Raniganj) consists of sandstone and shale without conglomerate; its coal seams are less irregular than those of the Barakar. The whole of the Lower Gondwana to the top of the Panchet is practically conformable, the apparent lack of conformity at some localities being due to overlap.

The Barakar coal seams are, for the most part, poor in quality but vary in that as well as in thickness. At one locality, in northern part of the field, is a seam, 34 feet thick, with three benches of coal, 7, 14 and 11 feet, but the coal is poor and slaty except in one part of lowest bench. This great deposit can be traced for only a short distance and it thins away rapidly in all directions. Many thick seams were seen west from Barakar River. "These seams, however, seldom appear continuous over the whole area of the field; they can often not be traced for more than a few hundred yards and the quality of the coal may (and in general does) vary within even shorter distances." In one case a seam, 13 feet thick, divides into two within 50 yards, and the lower division soon is replaced with sandy shale. At times, sandstone and shale replace the coal for considerable distances. "Ballcoal" is not rare and the concentric laminæ are crossed by laminæ of the enclosing coal.

The Raniganj seams are less irregular and contain less shale. Blanford saw one 22 feet thick which was without parting, but ordinarily there are two or more benches. As a whole, the coal of this formation must be regarded as inferior; the 17 analyses show 8.50 to 35 per cent. of ash; only two samples had less than 10 and 6 had

more than 20 per cent. As the samples were clearly supposed to represent the average coal mined, they mark only the best and serve to indicate the general inferiority.

The *Aurunġa* and *Hutar* fields are somewhat more than 100 miles west from the Raniganj field. There, according to Ball,[18] the Lower Gondwana is overlapped by the Machadeva or Lower Jura, which, west from the Aurunga River, rests on metamorphic rocks. There is no coal in the Talchir. Ball thinks that the Karharbari coals belong to the Talchir rather than to the Barakar, though the associated rocks are similar to those of the Barakar.

In the Aurunga field, the Barakar deposits are sandstone grits and conglomerates with huge seams consisting mostly of carbonaceous shale, which occur "at various horizons and with most irregular lateral expansion." The deposition was confused; overlaps are frequent; changes in character and thickness of individual deposits are abrupt; pebbly conglomerates pass into breccias. The Barakar is about 1,500 feet thick in this field and the coals are of inferior quality. In the Hutar field, the Talchir is overlain on the western side by conglomerates and sandstones, resembling those of the Lower Jura. Coal is present in the Barakar on the Dauri River and westward, but it is wanting east from that river. The great irregular seams are not here but, instead, there are thin seams, often yielding good coal; these are intercalated in the sandstones within a vertical space of about 200 feet.

In both fields, the Barakar overlaps the Talchir and the seams of coal and shale are often of notable thickness. In a section near Rajbar, only 271 feet long, Ball measured 9 seams, about 10, 12, 83, 7, 13, 13, 21, 12, 24 feet, consisting mostly of carbonaceous shale with many streaks of poor coal. A sample from one seam, which looked like good coal, had only 22 per cent. of fixed carbon but 50 per cent. of ash. Similar conditions exist on the Sukri River near Toobed, where two seams were seen, 77 and 36 feet thick. This coal zone thins away toward the southeast. A zone of rippled sandstone was seen near Toobed. In the Hutar field there are four seams, 1 foot 3 inches to 8 feet thick, with much carbonaceous shale

[18] V. Ball, "On the Aurunga and Hutar Coal-Fields," *Memoirs,* Vol. XX., 1880, pp. 1–127.

in each, but there is a greater proportion of good coal than in the Aurunga field. The ash in analyzed specimens is from 7.8 to 18.2 per cent., whereas in the Aurunga field it is 15 to 34 per cent. The rocks of the Hutar are as irregular as in the other field. The Raniganj consists chiefly of soft yellow false-bedded sandstone and contains a coal seam, one foot thick. Its coal has 2.5 per cent. of ash.

The *Ramkola* and *Tatapani* coal fields, west from the Hutar field, are part of a strip extending westwardly about 200 miles to Jabalpur on the Narbudda River and thence southeastwardly about 300 miles to near Sarbalpur on border of the Talchir field in Orissa. Griesbach[14] states that Talchir, very irregular in occurrence and filling hollows in the metamorphic rocks, consists of clays and sandstones with conglomerate at top. The extreme thickness is not far from 900 feet.

The Barakar, consisting largely of micaceous sandstone, often flaggy, often crossbedded, contains some variable coal seams, which occur in three zones, two midway in the formation and the other directly under the Raniganj. In one of the middle zones, he saw a seam, 7 feet thick, but within a short distance it is but 3 feet 6 inches, while farther west the horizon is represented by 17 feet of black shale with streaks of coal. This kind of variation seems to be characteristic of the Barakar coals. The formation is not more than 900 feet thick; its coal is practically worthless and much of it is lignitic. The Raniganj, about 1,200 feet thick, is made up of white feldspathic gritty sandstone and white shale. No coal has been discovered. The Barakar in this area is characterized by *Glossopteris communis, G. browniana, G. damudica* and *Vertebraria indica;* but the Raniganj has *G. communis, G. angustifolia* and *G. retifera.*

The *Wardha Valley* field is about 175 miles southwest from the last. It was examined by Hughes,[15] who found the Talchir and Barakar clearly defined but the ironstone shales and the Raniganj are indefinite; the term, Kamti, is applied to the rocks occupying

[14] C. L. Griesbach, "Geology of the Ramkola and Tatapani Coal-Fields," *Memoirs,* Vol. XV., 1880, pp. 129–192.

[15] T. W. H. Hughes, "The Wardha Valley Coal-Field," *Memoirs,* Vol. XIII., 1877, pp. 1–154.

the interval. Talchir, without coal, has the same features as in eastern fields; Feistmantel found fronds and seed vessels of *Gangamopteris,* which he separated from *Glossopteris.* This plant occurs also in the Barakar.

The Barakar is only 250 feet thick, whereas in the Jheria field it is 3,300. Coal is confined to a band near the top. At one locality, a boring pierced a seam, 48 feet thick, with 3 benches of coal, 30 feet, and 4 benches of coal and shale; coal taken from a bench 15 feet thick, proved to be good as fuel, but it splits on exposure and when wetted it crumbles. At another locality, the seam is almost 59 feet, with 44 feet of coal, but ash is almost 23 per cent., though there is some "less bad" coal in one portion with only 18. At still another locality, the seam is 81 feet, in two main benches, 37 and 32 feet. A specimen yielded 14.5 per cent. of ash. This mass, though generally thick, shows extreme irregularity and in many borings no trace of it exists. Hughes was not prepared to decide whether the explanation is to be found in erosion or in non-deposition, but was inclined to accept non-deposition, for many outcrops show the attenuated border of deposition, containing only shale with no disintegrated coal. The Barakar coal is bituminous, but, as a rule, it is inferior because high in ash and sulphur. No coal has been seen in the Kamti. No marine fossils have been discovered.

The southern part of the *Sátpura-Gondwána* Basin is about 140 miles north from the last and about 50 miles farther west. According to Jones,[16] the Talchir here is as in the fields at the east. Barakar coals are present in the numerous petty basins and the seams vary from a few inches to 11 feet; but the thicker ones are divided by clay partings. Occasionally, the coal has a sandstone roof. Mining is insignificant and there is nothing in the character of the coal to justify exploitation; analyses from six localities showed 17 to almost 49 per cent. of ash and only one specimen caked.

The Narbudda River reaches the Gulf of Cambay on the west coast of Hindostan near the 22d parallel; the *Narbudda District* is on the lower part of the river and is west from the Sátpura region.

[16] E. A. Jones, "Southern Coal-Fields of the Sátpura Godwána Basin," *Memoirs,* Vol. XXIV., 1887, pp. 1–58.

In the central part of the district, Medlicott[17] grouped the Permo-Carboniferous into Talchir, Lower and Upper Damuda. The Talchir has the familiar features and at most is about 600 feet thick.

The Lower Damuda (Barakar and Ironstone shales) has an extreme thickness of not far from 1150 feet. The rocks are mostly sandstone and sandy shale, but there is a considerable proportion of black shales. At times, the sandstones are rippled and often are crossbedded. The deposition was irregular; sandstones pass to shale abruptly. *Glossopteris, Vertebraria* and *Phyllotheca* are abundant at several horizons. The coal seams, for the most part are thin and, with one exception, are without value, while, at best, they are mere lenses. The Upper Damuda (Raniganj), about 150 feet thick, is composed of irregularly bedded clays and clayey sandstones. The coals are thin and of indefinite extent. A section obtained at the junction of the Machariva and Sher Rivers and extending 150 yards, illustrates the conditions:

(1) Sandstone not measured; (2) good coal, 3 inches; (3) soft sandstone, 3 feet; (4) coal seam, consisting of black micaceous shale, 6 inches, coal 2 feet, shaly coal, 6 inches, in all 3 feet; (5) hard sandstone, 3 feet; (6) blue clay, 4 feet. The black shale of (4) is cut out quickly by (3) and the shaly coal of (4) disappears within a few feet, while (2) and (3) are replaced with clay before the end of the exposure has been reached. *Glossopteris* is wanting in the Upper Damuda, its place being taken by cycads. The coal seams are wholly unimportant.

The Talchir beds in the *Thilmille* coal field of Sergúja have a thin seam of coal; but as a rule this formation is distinguished by absence of coal and even of carbonaceous shale. The Kharharbari coal group was included originally in the Barakar, but it was placed in Talchir by Medlicott and Blanford[18] because of the intimate relation of the flora.

In studying reports on the several coal fields one cannot fail to be impressed by the thinning of Raniganj, Barakar and Talchir from

[17] J. G. Medlicott, "On the Geological Structure of the Central Portion of the Narbudda District," *Memoirs*, Vol. XIII., 1877, pp. 155–248.

[18] H. B. Medlicott and W. T. Blanford, "Geology of India," Calcutta, 1879, pp. 109–112.

east to west; the apparent exception in the Narbudda district is only apparent, for Raniganj and Barakar are counted as one and the Panchet or Trias is the Upper Damuda. Equally noteworthy are the great irregularity and evidently local character of the coal seams, which are hardly less striking than the small proportion of high-grade coal in all of the fields.

Siberia.

Carboniferous deposits are exposed in broad areas within the Kirghiz Steppes of western Siberia.[19] There, according to the synopsis published by the Comité Géologique, the Lower Carboniferous rests at times on the Devonian, at others on the metamorphics. The lower portion is mainly limestone, but higher in the section the prevailing rocks are gray or green calcareous sandstone, with marine fossils similar to those of the limestone. This portion, however, varies greatly; in some localities it is chiefly shaly sandstone while in others it is mainly black clay shale.

Directly overlying the Lower Carboniferous is the Coal series, consisting of alternating white, gray to black, more or less sandy shale, with yellow to green and white clayey sandstones and some seams of coal. The white to gray sandstones occasionally become conglomerate, but only in limited areas. The only fossils are plants, which occur abundantly in the roof or near the coal; but these are ill-preserved and, in large part, only the genus can be determined; the flora, however, is distinctly Upper Carboniferous.

The coal-bearing rocks are in valleys, enclosed by older deposits and in most localities are greatly disturbed, though the disturbance is comparatively slight in a few areas. The variation in thickness of coal seams is almost as notable as in those of India. Borings made near Ekibas-touz, under supervision of the government geologists, revealed the presence of two seams, 23 and 40 meters along a line of 7 versts; but elsewhere the total of coal rarely exceeds 6 meters and, too often, the seams are merely alternating thin layers of coal and coaly shale, practically worthless for industrial purposes. The district between the Irtych and Ichim Rivers, south and west from

[19] Aperçu des Explorations Géologiques et Minières le long du Transsiberien," le Comité géologique de Russie, 1900, pp. 27–32, 52, 83–88.

Pavlodar on the Irtych, is marked by great irregularity in the seams; at Tyn-koudruk, one, 2 meters thick, thins away like a wedge, while another near by has coal charged with sand and thins away rapidly. Generally speaking, the seams are inconstant, at times swelling abruptly and at others disappearing. The variations do not appear due to the disturbance. The coal horizons, of which many were examined, occupy very limited areas. Some clean coal was seen, but there is little of it.

Eastward from the Ob River, one is beyond the Kirghiz Steppes. In the space between that river and the city of Atchinsk, the Lower Carboniferous is exposed frequently with, in general, the same features as farther west, except that some of molluscan forms found in the Ural region are wanting. The coal formation is triple and the seams are in the middle division, which consists of clays, shales and sandstones, with many remains of *Neuropteris* and *Cordaites* as well as *Anthracosia, Posidomya, Carbonicola* and other mollusks. The basin has an area of not far from 15,000 square kilometers and has many seams of coal but no attempt to develop them has been made.

An important basin is crossed by the railroad in the Jenessei region. Near Soudjenka, 130 kilometers from the city of Tomsk, this is 5 kilometers wide. It extends many miles northward, narrowing to disappearance; but it was followed for a much longer distance toward the south, with constantly increasing width. The dip is high, rarely as low as 10° and frequently as much as 60° to 90°. Nineteen seams of coal were seen, more than 0.75 meter thick, one of them 11 meters. The coal, mined somewhat extensively near Soudjenka, is much the same at all horizons; by some it would be classified with anthracite, while others would call it caking coal. Seams were seen at many localities on the Upper and Lower Angara River, north from Irkoutsk, everywhere characterized by irregularity of occurrence. The coal of this central region is much better than that of the Kirghiz Steppes, samples from Soudjenka and the Angara yielding only 3 to 6 per cent. of ash.

Cannel, 0.5 meter thick, was seen on the Ichim River, 60 miles north from the railroad.

Carboniferous deposits seem to be wanting in the region east from Lake Baikal.

Russia in Europe.

Murchison[20] believed the Carboniferous System of northern and central Russia to be equivalent to the Mountain Limestone and underlying deposits of Great Britain, while, on the western slope of the Urals, he recognized the Millstone Grit and Permian. In the Valdai Hills, Province of Novgorod, the Lower Carboniferous consists of, ascending,

Lower Limestone, with *Productus gigantea,* associated with sands and some coal beds; Moscow Limestone with *Spirifer mosquensis;* it has no coal in northern and central Russia, but there are seams in the southern Steppes; Upper Limestone, with *Fusulina cylindrica,* containing coal only in the southern Steppes.

The sands at base of the Lower Limestone have many pyritized plants, among them *Stigmaria ficoides;* bituminous shales associated with the sands contain coal. Those on the Pritchka River are 40 feet thick and contain 4 coal seams in the upper portion. The coal is extremely imperfect and is from 10 inches to 4 feet thick. Helmersen had described this as Moorkohle; it is impure, pyritous, slightly consolidated and is inferior to some Tertiary coals mined in portions of Germany. The cover is largely loose sands and variegated marls.

Nikitin[21] states that the lignite occurs in the Toula District near the Volga. The coal group, at same horizon as in the Valdai Hills, consists of alternating clays and sandstones with more or less considerable seams of coal. He thinks it strange that this material, in spite of its great age, has chemical and physical character so closely allied to that of lignite. Boghead, rich in oil, is present at several horizons. At one locality, several thin coals were seen at the base of the Lower Carboniferous, but they have insignificant lateral extent.

[20] R. I. Murchison, "Geology of Russia in Europe and the Ural Mountains," London, 1845, Vol. I., pp. 69–71, 78, 126.

[21] S. Nikitin, "De Moskau à Koursk," Guide des Excursions, XIV., St. Petersburg, 1897, pp. 4–7.

The Donetz coal basin in southern Russia was studied in 1892–94 by Tschernyschew and Loutougin,[22] who published a synopsis of their reports. The Basin occupies much of the provinces of Poltawa, Kharkow and Don Cossacks, and is drained by the Donetz River, emptying at northeastern corner of the Sea of Azov. The Carboniferous is exposed in an area of not far from 12,000 square miles, but borings through overlying deposits prove that the actual extent is much greater. The deposits are, as described by Murchison, in three divisions, but the highest one belongs to the Upper Carboniferous. The divisions are designated C_1, C_2, and C_3, in ascending order. The measurements by Tschernyschew and Loutougin are in great detail and the description notes the lithological character and fossil contents of each stratum. Condensed, the description is C_1, in its lower 4 subdivisions, consists of limestones and silicious marls, rich in marine fossils. Coal appears first in the 5th, composed of gray micaceous sandstone with subordinate beds of limestone, arkose and shale; the coals are thin. C_1 is characterized by *Productus giganteus*.

C_2 begins with a mass of sandstone, shale and limestone, in which *Productus giganteus* is wanting and *Spirifer mosquensis* is the notable form. Coal occurs in the second subdivision, but the seams rarely attain workable thickness. The third, shales, sandstones and insignificant limestones, has 9 coal seams from 0.35 to 0.75 meter thickness; though rarely reaching the maximum and varying greatly in thickness, several of these seams are mined extensively. At some localities they are excellent for coke, at others for gas, while at others they are anthracitic. Usually only one or two beds are "workable," but at Ouspenskoïé, there are 8. The fourth subdivision, 320 to 350 meters thick, almost wholly sandstone and shale, has 4 seams, rarely workable and often replaced with shale. The fifth, 250 meters thick and composed of sandstone and shale with about 6 meters of limestone, has 8 seams and is richer in coal than are the lower subdivisions, though the seams are very irregular. The extreme thicknesses in the important seams are 0.7 to 1 meter, but these in some cases thin away to insignificance. The sixth, 225

[22] T. Tschernyschew and L. Loutougin, "Le Bassin du Donetz," Guide des Excursions, XVI., 1897, pp. 4–10; 12–23, 27–29, 34, 50.

to 300 meters, is the most important coal-bearing portion. Of the 11 seams reported in the section, 8 have a maximum of 0.7 to 1.75 meter inclusive of partings. Marine fossils were observed in the roof of 5 seams.

C_3, about 2,000 meters thick, contains workable coal only in the lower horizons. The fauna changes gradually; forms of the middle division disappear and new forms appear, which are characteristic of the Upper Carboniferous in Timan and in North America. The lowest subdivision has 10 seams, but all are thin and the coal is poor. In one case, the roof contains marine fossils. Red to green shales are in the upper part of the section. The second is separated from the first subdivision by 11 meters of marine limestone and contains 2 or 3 coal seams, which are wholly unimportant. Arkose near the base has fragments of *Araucaria* and the section shows some green and red shale. The third subdivision has only thin streaks of coal and thin beds of red shale. The fauna and the flora are distinctly Upper Carboniferous.

The number of coal seams, which, at some place, attain workable thickness, is not more than 30; but the variability both in thickness and in quality is extreme; some disappear, others become thin and worthless while new ones appear. The coal loses volatile in the direction of increasing dip. At mines in the Almazny seam, along a northwest-southeast line, only 20 miles long, the volatile is 35, 30, 25, 18, 15 or less per cent. The proportion of volatile has no relation to nature of the roof or floor. The authors regard the Donetz coals as allochthonous, the convincing argument being the presence of marine fossils in the immediate roof of coal seams.

Permo-Carboniferous deposits are confined to the western side of the Donetz Basin, where they rest directly on the limestone closing-C_3. Deposition was continuous from Carboniferous to Permian and there is no evidence of unconformity anywhere. The deposits are regarded as Lower Permian and the abundant marine fossils are in greatest part forms characterizing the C_3, the Upper Carboniferous; the change in fauna is as gradual as that in passing from C_2 to C_3. The lower portion consists of clayey shales and gray, green or red limestones with some streaks of coal near the base. The upper portion consists mostly of red and green marls

with deposits of salt and gypsum. Some dolomites, regarded as equivalent to the Zechstein, were seen at one locality. These contain a Permian fauna. Disturbance followed the close of the Permian, and the overlying rocks are notably unconformable, occupying valleys in the eroded Paleozoic rocks.

Conditions in the southern Urals are much as in the Donetz Basin. Murchison[23] described them in his great work on Russia. At a later date he gave a synopsis of his conclusions, in which he states that the Permian deposits "occur in almost apparent conformity to the Carboniferous rocks." Coal appears to be wanting in Urals but the lower division contains streaks of impure coal in the central region between the Urals and the Volga River.

Spitzbergen.

Nathorst[24] has given in summary the results obtained by himself and others during exploration of the Spitzbergen region. The whole series from Lower Carboniferous to the Permian is present. The Lower Carboniferous, which is represented by the Kulm, rests unconformably on the Devonian. It consists, at base, of dark quartzitic sandstone, underlying yellow sandstone, on which rests a mass of bituminous clays and shale with fragments of ferns and, in the lower part, a thin seam of coal resting on a *Stigmaria* underclay, containing sphaerosiderite. Above this mass of shale and clay are sandstones, yellow and white, becoming red in the upper portion, showing coaly streaks at some places and at others lenses of coaly shale resting on *Stigmaria*-clay. The lens form is due to compression. The dip approaches 90°. The petrographic characters as well as the fossils indicate that the Kulm beds were deposited in shallow fresh-water. They suggest swamps at mouths of rivers.

The Kulm beds are followed by a mass of limestone, which, at base, shows transition to the Upper Carboniferous, and at top to the Permian. The system closes with rather loose marls and sandstones, holding less than 2 meters of limestone in the thickness of

[23] R. I. Murchison, "Siluria," 3d ed., London, 1859 p. 325 et seq.

[24] A. G. Nathorst, "Beiträge zur Geologie der Bären-Insel, Spitzbergens und des Konig-Karl--Landes," *Bull. Geol. Inst. Upsala*, Vol. X., 1910, pp. 321, 323, 325, 327, 330, 337, 347–350.

more than 30 meters. The total thickness of Carboniferous may be not far from 1,000 meters, as the maximum; but the several members vary greatly. Nathorst shows that throughout the whole section deep-water deposits are wanting. The Kulm, in greatest part, is of fresh-water origin; the limestones, beyond doubt, were laid down in shallow water during the long-continued slow subsidence of the area. The fossil wood is of a type indicating a sub-tropical climate. The deposits are conformable, the only irregularity being due to overlap.

Silesia.

The Upper Silesian Coal Field.—This extremely important field is between meridians 18° and 20° and is divided toward the southern border by the 50th parallel. In greatest part, it is within Prussian Silesia, but it extends eastwardly into Galicia and westwardly into Austrian Silesia. The area is almost 4,000 square miles, of which 2,400 are in Prussia. The great economic importance of this field has led to many careful and more or less detailed studies during the last eighty years. According to Dannenberg,[25] the deposits have been grouped into

V. Saarbrück Stage	Sohrau beds	Karwin or Orzesch beds	
IV.	Nikolai bed		
	Ruda beds		
III. Sudetic Stage (Waldenburg)	Sattelflötz beds		
II.	Czenitzer beds	Rybnik beds	Ostrau beds
	Loslauer beds		
	Hultschun beds		
I. Lower Carboniferous	Golonog beds	Petrzkowitz beds	
	Kulm		

The Ottweiler stage is wanting and the presence of Permian is uncertain. The grouping is essentially that offered by Gaebler in 1898. Somewhat later, Michael[26] used other terms: Instead of Saarbrück he employs Mulden, as it occupies the central part of the field; Satterflötz is replaced with Sattel-group, while the Ostrau

[25] A. Dannenberg, "Geologie der Steinkohlenlager," Erster Teil, Berlin, 1908, pp. 170–172, 180–197.

[26] R. Michael, "Die Gliederung der oberschlesische Steinkohlenformation," *Jahr. k. k. preuss. Geol. Landesanst.* Band XXII., 1902, pp. 319–340.

beds are termed the Rand group because they are on the border of the field. The Rand or Ostrau beds form the Schlesische Stufe.

Dennenberg has given a careful synopsis of his observations and of those by other students in this region, which may be utilized here. The thickness of the Saarbrück and Sudetic stages is, at most, not far from 7,000 meters; but the coal is distributed unequally. The Sattelflötz, at most barely one-twenty-eighth of the whole mass, contains about one fifth of the workable coal. The deposits decrease toward the north and east, the Sudetic mountains being the source whence the sediments were derived. The Sattelflötz beds near Zabrze measure 240 to 250 meters but at the east, on the Galician border, they are only 14 to 15 meters. According to Gaebler, the Ostrau or sub-Sattelflötz beds are 4,000 meters thick near Ostrau at the southwest, but only 500 meters near Golonog on the extreme northeastern border of the field. The total of Upper Carboniferous diminishes from about 7,000 meters at the west to barely 1,220 at the east. This thinning of sediments leads to frequent disappearance of intervals with resulting union of coal seams and relative enriching in coal-content.

The Upper Carboniferous rocks in this field are remarkably uniform in general character; sandstones, mostly white, prevail; while shales are subordinate and become important only in the highest division. Clay ironstone is present in nodules or in workable beds. Conglomerates are insignificant and red beds are practically wanting. The maximum thickness of the several divisions is Saarbrück (Karwin or Orzesch), 2,700 meters; Satterflötz beds, 240 meters; Ostrau beds, 4,070 meters. The total of coal is 299 meters, of which only 169 are in workable seams.

But emphasis must be laid on the fact that this statement of coal resources is merely general and is the maximum. The number and thickness of coal seams vary from place to place; the Ostrau beds are usually barren in the northern parts of the field, but there are a few seams which occasionally become workable. The Satterflötz beds, "the glory of the field," show extreme variation. They are exposed by anticlines in the neighborhood of Zabrze, Konigshütte and Myslowitz, but elsewhere in the greater part of the Prussian area they are buried deeply. The chief expansion is at Zabrze on

the western side but thence, northward and eastward, the changes are as interesting as those in the Anthracite region of the United States. Five seams are mined at Zabrze; but just west from Beuthen, one finds that the thick parting between numbers 1 and 2 and the interval rocks between 4 and 5 have disappeared; at Konigshütte, the 3d seam has become united to 4 and 5, so that now there are but the Upper seam, representing 1 and 2, and the Lower seam, representing 3, 4 and 5. But, at a short distance farther west, near Kattonitz, these two seams are so near together that they are mined as one. At the west, the coal of Sattelflötz beds is to the other rocks as one to nineteen, but at the eastern border it is thicker than the other rocks. Whether or not the newer seams overlap the older ones after union does not appear from the reports.

The same features are shown by the Saarbrück complex, which is present chiefly in the central portion of the field. Near Nikolai, Sohrau and Pless, it is 2,667 meters thick, with at least 253 coal seams, 45 being workable with about 75 meters of coal; but near Beuthen, 20 miles north, the Ruda beds, which near Nikolai are 589 meters thick with 49 meters of coal, are only 248 meters with 11.93 of coal; while in the Galician region the whole Saarbrück is but 1,014 meters with 35 seams and somewhat more than 60 meters of coal. The Ostrau-Karwin region is in Austria. The Ostrau beds occupy the Ostrau trough and most of the Peterswald. The Sattelflötz beds, as shown by Petrascheck and Mladek since the publication of Dannenberg's work, are present in the west side of Karwin trough, passing under the Saarbrück farther east. Marine deposits are characteristic of the Ostrau beds here as also in the northern areas. The number of coal seams is great and the quantity of coal makes the district important—in contrast with the other districts, where the Ostrau coals are almost unimportant.

Goeppert,[27] three-quarters of a century ago, studied the Silesian and Galician portions of this region. His investigations were made largely from the paleobotanist's standpoint, so that he had little interest in correlation and still less in economic studies.

Conglomerates are not wanting but the pebbles are rarely larger

[27] H. R. Goeppert, "Abhandlung eingesandte als Antwort auf die Preisfrage, etc.," Leiden, 1848, pp. 107–206.

than a pea; the prevailing rock is sandstone, gray to yellow, which in some localities weathers to a carved or fretted surface. It is quartzose and has little cementing material. Clay shales are intercalated in the sandstone mass and they are associated with the coal seams. Near the coal, these shales often are rich in bitumen, becoming Brandschiefer and frequently containing much pyrite. Irregularity of deposit is evident from the rapid change of sandstone into clay shale. Sphaerosiderite occurs chiefly where the coal seams are thin and alternating with shaly clays.

This region is marked by the thickness, extent and regularity of the coal seams, according to Goeppert; but when he studied the area, the correlation was very uncertain. The thickness is from 3 to 12 feet, but at one locality it reaches 42 feet. About 20 seams are workable. Dips commonly are less than 12°, but near the Carpathians they are higher. The thicker seams are ordinarily in several benches, varying not only in thickness but also in character of the coal; some benches are caking, others, not. Laminated coal is the predominant type and occurs, as a rule, in the top and bottom portions; Grobkohle forms the best benches of thick seams and for the most part is confined to the middle, being found rarely in other parts; clean Pechkohle is less abundant and Blätterkohle seldom occurs. In great districts, every coal seam contains remains of plants, especially of *Sigillaria;* Faserkohle is in all seams and sometimes it predominates, making the coal loose.

At Zabrze, the seams [Sattelflötz] contain much Faserkohle; that material predominates in the highest, which is 13 feet thick. A sandstone quarry in the Brenz district, on the Poland border, has great stems of silicified wood—an unusual occurrence in the Upper Silesian field. Near Myslowitz he saw *Sagenaria* stems standing on the coal, one of them 4 feet high and 2 feet in diameter. In the Locomotive mine, there, erect *Sigillariæ* are abundant in the roof of the coal seams. On the Poland border, the lowest seam near Dabrowa is 78 feet thick, divided midway by 6 feet of Brandschiefer, consisting of compressed *Sigillaria* associated with a little clay. The same *Sigillaria* is in the coal along with Faserkohle. Goeppert states that the *Sigillaria* is incredibly abundant.

At Zawada in the Nikolai district [Saarbrück], the Friedrich

mine works two seams, 24 and 60 inches thick, separated by an interval of 48 to 54 feet. The lower yields a laminated, hard, coking coal but coal from the upper one was considered to be inferior. When the lower seam was almost exhausted, work was begun on the upper. Its coal resembles Blätterkohle, consisting of hard, glance-like lamellæ alternating with thinner dull laminæ, composed of compressed barks of *Lepidodendron, Calamites, Stigmaria* and *Sigillaria,* all distinct. Goeppert states that, in many ways, this resembles peat. At a mine in this Nikolai district, the coal contains great abundance of *Sigillaria* and *Lepidophloios* and an "incredible" mass of *Sigillaria* is in the roof. There he obtained *Sigillaria* and *Alethopteris* with leaves only slightly brown and completely flexible, preserving the minutest details of structure. Union of coal seams is a familiar feature in the Nikolai district. Additional observations by this author will find place in another connection.

Goeppert makes only passing reference to the Austrian part of the field; but material information respecting one portion has been given by Petrascheck[28] in a paper dealing especially with the Peterswald trough, lying between the Ostrau trough at the west and the Karwin trough at the east. With Stur and Gaebler, he recognizes Ostrau beds in the western part of the trough but he finds the Sattelflötz beds in the eastern portion, where the disturbance was so severe as to cause inversion. A serious difficulty encountered in correlation was found in the sudden changes in character as well as thickness of the deposits, which mark some horizons more than others. It appeared to him that the Ostrau beds were deposited on a rudely level oscillating coast, so that paralic and limnic conditions alternate. In discussing the evidence of overturned stratification, he presents some facts which have interest here.

The layer of "Schramm," soft, more or less clean coal, passing at times into shale, is, as a rule, on the floor of the coal seams; occasionally, it is found in the body but very rarely on top of the coal. In the Sophien coal mine, all coal seams have the "Schramm" on top, the 'Faux-mur having become the Faux-toit. Reed-beds or underclays with *Stigmaria* appendages crossing the bedding, are the

[28] W. Petrascheck, "Das Alter der Flöze in der Peterswalder Mulde, etc.," *Jahrb. k. k. geol. Reichsanst.,* Band 60, 1910, pp. 779–814.

roof, not the floor of the seams in their present position. In one seam, upright stems stand on the coal, in the present floor, but original roof. The note on Cannel is worth citing, as it indicates unusual conditions in the area. There one finds in the upper seams of the Ostrau as well as in the Karwin seams, lenses of cannel or of dense cannel-like Brandschiefer, "Sklok" of the miners. Petrascheck states that, as a rule, this is the top of coal seams; he knows of only one instance where it is at the bottom. This he regards as the ordinary condition in coal regions, thus taking issue with Potonié, who maintains that it occurs usualy at the bottom of seams. But in the American coal areas, cannel is found in any part of coal seams, just as the analogous material is found in peat deposits.

The Sattelflötz area, farther east, is thick, consisting mostly of sandstone and arkose with intercalated beds of red sandstone. The important coal seams have been correlated definitively with the main seams of the same group in upper Silesia. The evidence was obtained in three borings. Marine forms are present at 20 feet below the Prokop (Pochhammer) seam and they mark the top of the Ostrau. At Justin, the coals have local cannel in Hangend. Splendid, widespreading, branching *Stigmaria* are in the floor of the Ivan seam, associated with sphaerosiderite. Seam II. has cannel-like coal near the top, covered with black coal, underlying a shale with marine mollusks. Erect *Sigillaria* were seen in the roof of the Hermann seam.

At the Albrecht shaft, the Eugen seam has many prostrate as well as erect stems in the roof and indistinct *Stigmaria* are in the floor. Stur found pebbles in this coal. Long ago, Bartonic collected from a dark shale in this seam a marine fauna, *Nucula, Pleurotomaria,* and *Orthoceras* as well as *Anthracomya.* The Koks seam contains plant-bearing concretions of iron stone and a layer of shale with similar concretions rests directly on the coal; it too has a marine fauna. A sandstone near the Koks seam has so great number of stems of *Lepidodendron* and *Sigillaria* that Petrascheck regarded it as a strand formation. Pebbles were seen in the younger Ostrau coals. They are numerous in the Josefi coal, granite, porphyry and quartz; they are present also in the Kronprinz seams but are smaller than in the other. Erect stems occur in the

roof of the Juni seams. Cannel-shale and sphærosiderite are characteristic and several marine horizons were observed.

Petrascheck[29] has called attention to the occurrence of coal pebbles in a sandstone at Brzescze in the Galician area. This sandstone, containing many fragments of *Sigillaria,* is shown in the Andreas shaft and belongs to the Upper Schatzlar [Saarbrück]. This sandstone for the most part is moderately coarse, but, where the pebbles of coal occur, the grain is coarser, almost conglomerate. Many of the coal fragments are well rounded, others have rounded angles while in others the edges are still sharp. Along with these are streaks of coal, insignificant in extent, and fragments of shale were seen. The lamination of the coal pebbles does not coincide with that of the sandstone. The largest pebble seen measured 6 by 5 by 3 centimeters.

The fragments include glance and laminated coal as well as cannel and show the peculiarities of each type; glance fragments are sharply angular but those of cannel and laminated coal are more or less rounded. Petrascheck is convinced by the form and structure that these were not balls of peat or pieces of wood, when entombed. For him, the evidence indicates clearly that the several types of coal seen in the pebbles had attained their characteristic features in Carboniferous time. The fragments are unquestionably of Canboniferous age for no older coal-bearing series exists anywhere in the surrounding region; but the source has not been discovered.

The Lower Silesian-Bohemian Basin.—One reaches this basin at about 150 miles north of west from the Upper Silesian field. The area is not far from 750 square miles; originally it was open toward the southeast, but was closed at the north and west by the Riesengebirge and at the east by the Eulengebirge. The northwestern and eastern portions are in Silesia but the southwestern, including much of the interior basin, is in Bohemia. The region was studied in great detail by Goeppert and recently Dannenberg[30] has summarized

[29] W. Petrascheck, "Das Vorkommen von Steinkohlengeröllen in einem Karbonsandstein Galiziens," *Verh. k. k. Geol. Reichsan,* 1910, pp. 380–386.

[30] H. R. Goeppert, "Abhandlung, etc.," 1848, pp. 207–275; A. Dannenberg, "Geologie der Steinkohlenlager," 1908, pp. 147–184.

the results of his own investigations with those of other observers. According to Dannenberg, the Lower Carboniferous of the Kulm stage is present in the Waldenburg district on the northern and eastern sides; it consists chiefly of coarse material but sandstone and shale are in the upper part, with occasional limestone. The colors are gray, brown and red. Organic remains are rare and the few animal remains belong to marine types.

The Upper Carboniferous, resting unconformably on the Kulm, is a monotonous accumulation of conglomerates and sandstones; these are usually almost white, but locally in rather wide spaces these beds, owing to infiltration of iron salts, are red and very similar to Rothliegende. The proportion of shale is remarkably small and it is found almost wholly in association with seams of coal. The divisions are

Radowenz beds	Upper Ottweiler
Schwadowitz beds	Lower Ottweiler
Schatzlar beds	Saarbrück
Waldenburg beds	Sudetic

Marine fossils are absent and the only animal remains belong to fish, phyllades and ostracoids, which may be either fresh-water or brackish water-forms. The Rothliegende boundary cannot be determined; Coal Measures pass upward gradually and, in the southwest wing of the basin, the similarity of the rocks is so great that Upper Carboniferous was mistaken by some observers for Rothliegende. Local discordance has been discovered here and there in the Upper Carboniferous, there being local gaps in the succession; similar discordance between Upper Carboniferous and the Rothliegende has been observed, but evidence of general discordance between Upper Carboniferous and Permian remains to be discovered.

Groups of workable coals are in all the stages, but they are separated by thick deposits of barren rock. The irregular deposition of the several stages and the notable variations in thickness of coals lessen greatly the importance of this field. No coal seam is persistent throughout the exposed area of its stage; each decreases in all directions from a maximum and not a few seams disappear. No definite relation exists between depth from surface and the

character of the coal; maigre and caking coals alternate, but in a general way there is more of fat coal in the higher than in the lower divisions. Formation of coal began during the Kulm, which, on the northern and northwestern border, contains streaks of anthracite, up to 10 inches thick, associated with coaly shale. But accumulation was unimportant prior to the Sudetic stage.

The Waldenburg (Sudetic) beds are the Liegendzug at Waldenburg; workable seams in the eastern part of this district are few, thin, dirty and varying much in thickness. Just beyond Altwasser, 16 seams were seen, of which 6 to 13 are workable in the several mines. Farther toward the south, only one seam is workable—and locally—near Tannhauser, the whole stage thins away. The seams are 10 to 50 inches thick.

The Schatzlar (Saarbrück) stage is the Hangendzug at Waldenburg and is separated by a thick practically barren interval from the Liegendzug. The rocks in this interval are conglomerates at base, passing upward into coarse sandstone with some shale and thin streaks of coal. These are overlain by the Hochwald porphyry, which is 834 meters thick west from Waldenburg. The rocks below the porphyry are the Weisstein beds of Dathe.[81] The Schatzlar stage is important chiefly near Schatzlar in the western part of the field within Bohemia. Northeastward from that locality to Landeshut the coals are insignificant; but toward the southwest workable seams are at Gottesburg. Along the northern outcrop in Prussia, the stage is unproductive, but at Waldenburg the seams are numerous once more and 12 to 15 out of the 40 shown in the section are workable with maximum thickness of 2 to 4 meters. But here as elsewhere workable thickness never occurs in any considerable space and important localities are practically isolated.

The Schwadowitz and Radowenz, representing the Ottweiler, are exposed in the southwestern part of the field, where the coal seams are of merely local importance. The succession, descending, is:

Radowenz, enclosing 5 to 7 seams, of which 2 are workable locally;

[81] E. Dathe, "Der Verbreitung der Waldenburger und Weisssteiner Schichten in den Waldenburgen Bucht," *Verh. d. d. Geol. Gesellsch.*, 1902, pp. 189–193.

Barren interval, "Hexenstein Arkose," alternations of arkose, conglomerates, sandstones, and clay shale, with stems of *Araucarites schrollianus* (beds of the petrified forest);

Schwadowitz beds with 3 to 5 seams, 2 of them workable locally.

The prevailing color of the Ottweiler is red, but in the clay shales it is gray.

Goeppert[82] described the remarkable accumulation of petrified stems in the Hexenstein arkose. This is exposed on a high sandy ridge, extending northwestwardly from Radowenz to beyond Schatzlar. The fragments, weathered out from the soft sandstone, are extremely abundant in an area of not far from 20 English square miles. All of the stems seem to be prostrate and lie in practical conformity to the bedding of the sandstone; but they show no evidence of transportation such as should be expected if they had been washed out from their place of growth. The conditions led him to believe that the fragments are the remains of an overthrown forest. Those lying exposed on the surface have diameter of 1 to 4 feet, with a round or oval section and they are not waterworn; the length is from 1 to 6 feet, though in some cases it is 14 to 16 feet. The stems belong to *Araucarites schrollianus* and *A. brandlingii.* Petrified stems are numerous near Schatzlar as well as at some other localities, but the great accumulation is at Radowenz.

In his earlier work on the eastern side of the field, Goeppert divided the area into two districts, Waldenburg at the north and Neurode at the south; but these are continuous. The dips are high, usually between 45° and 70° and the whole region was disturbed greatly by porphyry outbursts. Conglomerate, almost wholly wanting in the Upper Silesian Field, and coarse sandstone prevail; but these coarse rocks are not in contact with coal seams. The number of seams is greater than in the other Silesian field, but "rest periods," during which shales and coal accumulated, were brief and irregular; so that, while the maximum thickness of coal is great, the available quantity is comparatively small. In Upper Silesia, the coal seams consist chiefly of tree-like *Lepidodendron,* some *Sigil-*

[82] H. R. Goeppert, "Ueber den Versteinden Wald von Radowenz bei Adersbach in Böhmen, etc.," *Jahrb. k. k. Géol. Reichsan.,* Band VIII., 1857, pp. 725–738.

laria, a smaller number of *Calamites* and still fewer ferns; but in the field of Lower Silesia, though tree-like *Lepidodendron* and *Sigillaria* are not wanting, the prevailing forms are *Stigmaria, Equisetum* and ferns. Cannel-like coal occurs in the lowest seam.

From the Silesian-Bohemian line to beyond Altwasser, the Carboniferous rests on Transition rocks, but beyond Altwasser, usually on gneiss and mica schist of the Eulengebirge. In this, the Waldenburg district, the Hangend is red sandstone with occasional layers of limestone, containing fish remains but no plants; coal appears to be wanting but a black bituminous shale, 24 to 30 feet thick, is plant-bearing.

The lower coal group (Waldenburg) has many coal seams with a maximum thickness of about 43 feet, but the variations are great. A seam near Albendorf, 22 inches, splits into layers an inch to a half inch thick, of which the surfaces are covered with *Stigmaria ficoides.* Mineral charcoal is not abundant in this coal; the sandstone contain much petrified wood. Another seam, near Forste, yields a hard bituminous coal but the numerous clay parting make the seam almost unworkable; the coal contains *Stigmaria, Sigillaria, Sagenaria* and *Calamites.* The roof shale usually has a varied assemblage of plants, but at one locality *Calamites* is predominant. Goeppert saw, in the sandy roof of the highest seam, 4 vertical stems of *Sagenaria,* without roots, standing on the coal. In their interiors he found remains of *Calamites.*

Near Altwasser this group has 37 coal seams, but near Wäldchen there are only 2. Near Ober-Altwasser, 15 seams were seen, of which 6 can be worked, being 20 to 30 inches thick; but the dip is high, 60 to 70 degrees. Ordinarily, the coal in this neighborhood is laminated and, when split, the surfaces show *Stigmaria ficoides* as well as *Sigillaria, Sagenaria* and *Calamites.* The roof of seams 2 and 10 is, in each case, a mass of *Alethopteris* fronds, closely packed and associated with a very little clay. This condition was found persistent for 4,800 feet in one mine on seam 2. *Stigmaria* abounds throughout this lower group, not only in the clays, but also in the coal itself. Goeppert emphasizes many times the difference in species observed in superimposed coal seams as well as in the

same seam at different localities. Evidently there was localization of contemporaneous floras.

The upper coal group, above the Hochwald porphyry, has 80 seams of coal, 2 inches to 6 feet thick, but only 3 or 4 are workable, as partings are numerous. There are two subgroups, separated by a barren interval.

In the lower subgroup, he found resin by no means rare in seam 1; seams 4, 5 and 11 are caking; seam 6 has Sandkohle and seam 9 consists of Sinterkohle. Four has many thin layers of mineral charcoal; 11 is divided in distinct benches by partings of that material; but 5 has very little of it. The mineral charcoal is derived from *Araucarites* wood. *Stigmaria* is present in the coal at one mine; the upper bench of another seam contains *Sigillaria, Sagenaria* and *Stigmaria*. The southward prolongation of one seam has an abundant flora, which differs materially from that found in the northern prolongation.

The upper subgroup has 19 coal seams and the dip is 18° to 20°. The coal contains *Sigillaria, Sagenaria, Lepidophloios* and much mineral charcoal, the last in fragments up to 6 inches long. Resin is in the coal of a mine near Waldenburg. Erect stems of *Sagenaria* are in the roof of seam 9 and petrified wood was seen in a sandstone quarry. At the Sophien mines, the coal shows *Stigmaria* and *Sagenaria* on the surfaces of splitting; in the same neighborhood, another seam rests on clay, crowded with *Stigmaria* and its roof holds an abundant and varied flora. At the Fund mine in Charlottenbrunnen, the roof of a seam is a compact, fine-grained sandstone, in which he saw great prostrate stems of *Lepidodendron* and *Sigillaria,* 40 feet long and 30 inches in diameter. The floor has abundant *Stigmaria* and occasional *Calamites.* Many *Stigmaria* with some *Lepidodendron, Calamites* and *Noeggerathia* were seen in coal at the Segen-Gottes mine. The flora of this sub-group is most abundant, where the coal is thickest, but many types are confined to very restricted areas.

Similar conditions prevail in the Neurode district, where the higher deposits are reached. Near Buchau he saw in sandstone, several clumps of *Araucarites* stems, all apparently prostrate. Near

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Ebersdorf, erect stems, probably *Sagenaria,* stand on the coal. At Mölka, he obtained *Unio carbonarius* from a clay containing ferns and lycopods.

Hungary.

The coals of Hungary,[38] confined to the Banat region, belong to the highest part of the Upper Carboniferous and to the Rothliegende. They are unimportant and are present in four isolated districts, Eibenthal-Ujbánia at the east, Lupak-Gerlistye, Resicza-Szekul and Zagradia at the west. The deposits in the Ujbänia district are exposed in an area of not more than 800 by 1,700 meters and rest on gneiss and serpentine. Hantken's section, ascending, is

(1) Fine-grained sandstone, micaceous, with many ill-preserved plants, no ferns, but *Stigmaria ficoides* and *Calamites cystii,* 10 to 15 meters; (2) Donau coal seam, 1.5 to 14 meters; (3) porphyry, the immediate roof of the Donau and floor of the next seam, 30 to 50 meters; (4) Wenzel coal seam, 20 to 40 meters; (5) iron ore and porcelain jasper, underlying the Rothliegende conglomerate.

The Donau coal seam varies abruptly and frequently passes into a bituminous clay shale, known as "Brand"; when thick it is divided by 16 to 50 inches parting and laminæ of clay are so numerous in the coal as to make the product inferior; but selected coal is good, showing: water, 2.17; volatile matter, 14.64; fixed carbon, 79.75; ash, 3.62; and sulphur rarely exceeds 1 per cent. The coal is tender and the loss in mining is 50 per cent. The section at the Donau mine is: (1) Clean coal, 0.32; (2) parting, 0.20; (3) less clean coal, 1 meter; (4) coaly shale, "Brand" 20 meters. This seam disappears toward the west.

The Wenzel seam yields harder coal than that from the Donau, but it varies much in thickness and quality; only the upper portion is mined. The variation in thickness in both seams is so abrupt that systematic mining is impossible and the coal is taken out wherever it seems to be good.

No workable seam has been found in the Upper Carboniferous of the Lupak-Gerlistye district but the Rothliegende, consisting of

[38] M. Hantken, "Die Kohlenflötze, etc., der Ungarische Krone," 1878, pp. 24–44.

sandstones and clay shales, has some seams which occasionally attain workable thickness. Coal seems to be confined to the lower portion which is made up of mostly dark clay shale; the middle division is chiefly red sandstone but contains some dark shale, yielding plants; the upper division, red sandstone and micaceous shale, contains *Walchia, Taeniopteris, Pterophyllum, Callipteris* and other genera. The Zagradia district has no available coal.

The Szekul Valley is west from Resicza. The Coal Measures are exposed in a small area, where they rest on gneiss and underlie the Rothliegende. The boundary between Upper Carboniferous and Rothliegende cannot be determined as the passage from one to the other is exceedingly gradual, lithologically, and there is no unconformity. Four seams of coal are in the Coal Measures with maximum thickness of 0.75, 2, 1.50 and 1.30 meter, but the variations in thickness are so abrupt that, in each case, the coal is available in very limited spaces. The dip is not far from 45°, but changes in thickness are due in small degree to the disturbance. Partings are numerous; those of the third seam are blackband, which at times replaces the coal—in one mine this condition continued for 200 meters. The coal is very tender, barely 10 per cent. of lump coal being obtained. It yields a remarkably good coke; the ash is from 7 to 16 per cent., but washing removes about half of it. It is no longer necessary to resort to washing, as mixing the dust coal of Szekul with that from the Liassic coal of Doman gives a coke without excessive ash.

Bohemia.

Coal has been found in a number of more or less widely separated areas within western Bohemia as well as in one within the southern portion. The general succession throughout is so nearly the same, that many students in later days conceive that the western areas are merely fragments of a once continuous field, intimately related to the Saxony basins at the north, and that there may have been a connection with the Silesian areas at the east. As Dannenberg has said, they are all limnic, as appears from the irregularity of the deposits, including the coal seams, which thicken and thin, often wedge out and abruptly change in character; the coal seams,

few in number, vary greatly; the deposits were laid down in deep troughs on Cambrian and Pre-Cambrian rocks and decrease toward the middle line of the trough. The unevenness of the surface explains absence of lower members at some localities. The succession is Coal Measures and Rothliegende and the passage from one to the other is so gradual that no boundary can be determined; the relation of Upper Carboniferous to Permian was in dispute for a long time and, even now, the matter seems to be undetermined at several localities. Katzer and others of the older workers divided the deposits into the Radnitz beds at the base, belonging to the Coal Measures, followed by a Middle Zone, with the Nürschan coal seam, and on top, the Kounovaer beds; the last two were thought to be Permian. Borings made in areas where exposures are rare, led v. Purkyne[34] to a different conclusion. The succession in a boring made where the Pilsen Basin is deepest and where exposures are rare, is, descending: (1) Upper red clay shales, red and variegated shale and sandstone, 155 meters; (2) upper gray clay shales, with gray to white sandstone and coal seams, 180 meters; (3) lower red clay shales, red and variegated shale and marly shale with arkose, 52 meters; (4) lower gray shale, gray shale and gray to white arkose, with at least 9 coal seams, 419 meters. He thinks that earlier students had failed to recognize the existence of two red deposits, for no borings had been made and exposures are very rare. The Lubna coal seam and the Nýran cannel are at the same horizon. Each of the coal-bearing divisions, composed of gray to black shale and gray to white sandstone, underlies a division of red shales and sandstones, barren of coal.

Weitkofer,[35] in a review of the northern basins, grouped the Permo-Carboniferous deposits into: (*d*) Upper red clay shale, Lihnaer beds; (*c*) dark gray clay shales, Schlaner beds, containing the Pilsen and Schlan coal seams; (*b*) lower red clay shales, Teinitzler beds, 190 meters, with no fossils aside from stems of ***Araucarites;*** (*a*) gray sandstone group, Kladno-Pilsener beds, 300 to 400 meters,

[34] C. R. v. Purkyné, "Zur Kenntnisse der geologische Verhältnisse der mittelböhmischen Steinkohlenbecken," *Verh. k. k. geol. Reichsan,* Jahrg. 1902, pp. 122–125.

[35] K. A. Weitkofer, "Geologische Skizze das Kladno-Rakonitzer Kohlenbecken," the same, pp. 399–420.

with the Kladno Hauptflötz at base. The Lubna and the Nürschan coals belong to the coal group in lowest part of the gray sandstone.

Dannenberg[36] states that the Lower Carboniferous and the Waldenburg (Sudetic or Schlesische stage) are wanting and that the series begins with the Saarbrück, to which he refers the Kladno-Pilsen sandstones as equivalent to the Schatzlar beds of Silesia; but the upper part of those beds are now regarded as belonging at the base of the Ottweiler and as equivalent to the Schwadowitz beds.

The Teinitzler beds (Hexenstein of Silesia) and the Schlaner (Radowenz) represent the Ottweiler, and the Lihnauer are regarded as undoubtedly Rothliegende. The Saarbrück consists chiefly of thick sandstones and conglomerates; the Ottweiler is mainly red shales and sandstones, but it has much gray shale and white sandstone. The Rothliegende (Lihnauer) has its characteristic flora. Deposition apparently was continuous throughout and at some localities the higher beds distinctly overlap the lower. The Lubna-Nürschan coal seam is proved to belong to the basal coal group not only by stratigraphical relations but also by the associated flora, which is Carboniferous.

The several basins from north to south are the Kladno-Schlan-Rakonitz, which is west from Prag and north from the Bersum River; the Pilsen and farther south the small areas of Radnitz, Miroschan and Merklin.

The Kladno-Rakonitz basin, extending southwestwardly from Kralup to beyond Rakonitz, has a gross area of not far from 450 square miles (1,100 to 1,200 square kilometers), but the productive area is very much less. The stratigraphy is simple as it is not obscured by disturbance, the dip rarely exceeding 6°, except on the extreme border, where it becomes at times 15° or 20°. The largest coal seam, known as Grundflötz or deep Radnitz, is at the base, often separated by only a thin deposit from the older rocks. Locally it becomes 6 meters thick, but ordinarily it is so dirty as to be worthless.

The Hauptflötz or Upper Radnitz seam, 3 to 18 meters above the Grundflötz, has been traced for 60 meters along the strike and has been followed for 4 kilometers along the dip. It is extremely

[36] A. Dannenberg, "Geologie der Steinkohlenlager," pp. 232–257.

irregular. At both extremities of the basin it is too thin to be worked, but in two sub-districts, near Kladno at the north and Rakonitz at the southwest, it becomes workable; but even in these the variability is serious; a strip without available coal divides the Kladno district. In that district, the Hauptflötz at times rests directly on the older rocks, the Grundflötz being absent. It is in three benches with 3.75 to 5 meters of partings. In the eastern part of the district, the middle and lower benches are practically worthless, the ash being 26 to 28 per cent.; in the western portion the seam, 12 to 18 meters above the thick but worthless Grundflötz, is still triple, but the partings have become thin, so the whole mass, 9 to 12 meters thick, is mined as a single bed. In the Rakonitz area, the Hauptflötz occasionally has 4 to 5 meters of coal, but, especially toward the west, it tends to break up, so that there are few localities where it can be mined. Coal in the northern part of this basin is maigre and dirty, but near Kladno, it becomes fatter and at times less dirty: ash varies from 1 to 30 per cent.; caking coal is rare and cannel occurs at some localities.

Near Lubna, beyond Rakonitz, is the Lubna seam, of which Katzer[37] has given the section, which, descending, is: (1) Compact coal, in part brown, 0.30 to 1.10; (2) black clay parting, 0.03 to 0.20; (3) black cubical coal, 0.20 to 0.30; (4) compact brownish cannel with *Stigmaria,* 0.20 to 0.25; (5) thinly laminated Brandschiefer, with remains of ferns, 0.10 to 0.20; (6) clay with sphærosiderite, 0.20 to 0.50; (7) hard Brandschiefer, with remains of plants, 0.10 to 0.20.

The accepted reference of this seam, at the time when Katzer's work was published, was to the Permian, but later studies have proved that its place is in the basal portion of the Saarbrück and that the associated flora is Carboniferous, not Rothliegende. The presence of abundant *Stigmaria* in the cannel is worth noting. The same form abounds in a clay parting near Rakonitz.

The higher coal group, in upper part of the Schlaner beds, is separated from the lower group by the great mass of the Kladno-Pilsen sandstones, the Teinitzler beds and the lower portion of the

[37] F. Katzer, "Geologie von Böhmen." 2te Aufl., Prag, 1902, pp. 1118, 1158.

Schlaner beds, not less than 600 meters of rock. It is but a short distance below the Lihnaer red beds, belonging to the Rothliegende or lower Permian. Dannenberg calls this upper group "modest"; usually there are two coal seams, the upper, 0.5 to 1.04 meter and the lower, 0.3 to 0.4 meter thick, parting included in each case. Near Schlan, these seams are separated by an interval of 8 meters but, toward the west, they approach and finally become one seam, 0.4 to 1.7 meter thick. The coal is rich in volatile and contains about 14 per cent. of ash. The floor is a bed of sphærosiderite, with finely preserved plant remains. The roof is a Brandschiefer, termed "Schwarte," which approaches gas coal in composition but has no practical value. It has yielded a rich harvest of crustaceans, fish and *Stegocephalus.*

Lipold,[88] who believed that the Schlaner beds are Permian, has given the section of this bed as exposed near Schlan; it is:

(1) "Schwarte," 8 inches; (2) coal, 1 foot 8 inches; (3) clay, 3 inches; (4) coal, 1 foot 8 inches; (5) clay, not measured. This "Schwarte" is tender, black-brown Brandschiefer, so rich in bitumen that it ignites readily. Lipold asserts that it distinguishes Permian coal from that of the Coal Measures.

There are comparatively few exposures in the middle of the basin; borings, reported by Katzer,[89] show that the upper coal group is present on the western side. The borings begin in Rothliegende; the first reached biotite granite at 74.5 meters, that being the country rock. A coal seam, 0.49 meter, was pierced at 71.8 meters. In another boring, a seam of "Schwarte" and coal, 1.06 meter, was pierced at 89.59 meters from the surface, and was identified with that of the first boring. It underlies a clay shale and rests on dark clay shale, containing streaks of coal. An argillaceous sandstone at 17 meters from the surface contains fragments of *Araucarites* and appears to be in the undoubted Rothliegende. The boring ended at 23 meters below the coal seam, but did not reach the gran-

[88] M. V. Lipold, "Das Steinkohlengebiet in nordwestlichen Theile der Prager Kreises in Böhmen," *jahrb. k. k. geol. Reichsan.,* Band XII., 1861–2, pp. 507–509.

[89] F. Katzer, "Zur Kenntniss der Permschichten der Rakonitzer Steinkohlenablagerung," *Verh. k. k. geol. Reichsan.,* Jahrg., 1904, pp. 291–293.

ite; evidently the old surface was irregular and the overlap is notable, for only the highest part of the Schlaner beds is present.

The Pilsen Basin, not more than 30 miles south from Rakonitz and at extreme western extremity of the larger area has a total extent of not far from 150 square miles; the succession is practically the same as in the basin at the north, but the strata have endured much greater disturbance. Dips on the border reach 55°, though in the interior they sometimes become insignificant. The lower or Radnitz group shows 3 coal seams, known locally as the Fürstenflötz, Oberflötz and Unterflötz, the second and third being equivalent to the Hauptflötz and Grundflötz of the Kladno-Rakonitz region, while the highest seam is the same with that at Lubna near Rakonitz.

The variations in interval-thicknesses within this petty area are as remarkable as those proved by actual mining within the Anthracite fields on Pennsylvania. Dannenberg gives these measurements for opposite sides of the basin, separated by not more than 10 or 12 miles:

	Eastern Side.	Western Side.
1. Upper coal group.		
2. Interval	200	
3. Fürstenflötz	0.32 to worthless	0.5 to 1.15
4. Interval	15 to 132	17
5. Oberflötz	1.1 to 2.1	1.0 to 2.0
6. Interval	45 to 70	18
7. Unterflötz	1.8 to 4.4	0.5 to 1.0

The surface of the underlying rock is uneven, so that the Unterflötz is often wanting. The important seam is the Hauptflötz, which is usually 1 to 2 meters thick, but toward the north, occasionally swells to 3 or even 5 meters. The highest or Fürstenflötz is available midways in the basin, where it is known as the Nürschan cannel. Katzer[40] placed this in his "Middle Zone" and believed it to be lower Permian. He has given a detailed section of the bed as seen at Nürschan: (1) cubical black coal, 0.30; (2) black clay, 0.03 to 0.30; (3) cubical black coal, 0.30; (4) cannel, rich in *Stigmaria,* a few ferns, some bones; (5) Brandschiefer, thinly laminated, remains of ferns, some saurians and fishes, 0.25; (6) Platterkohle, in thick slabs, the chief source of saurian remains, with streaks of clay,

[40] F. Katzer, "Geologie von Böhmen," p. 1148.

0.30; (7) blattering [coarse] coal containing *Calamites,* replaced with pyrite, 0.08.

This section certainly bears close resemblance to that of the Lubna seam. The "gas coal" is usually shaly in structure but it passes into true cannel. It is clearly a lens as the thickness varies from a few centimeters to more than a meter. The Brandschiefer contains the remarkable Nürschaner fauna described by Fritsch and thought by him to be Permian, though its species differ from those of the higher deposit. The flora above it would seem to indicate an earlier age as it is very closely related to the Upper Carboniferous. According to Dannenberg, coal like that of Nürschan occurs occasionally, but locally, in the Unterflötz. The upper coal group, in the Schlaner beds, is unimportant; it contains two coal seams, but these are "workable" in only limited areas.

The Radnitz Basin, west from that of Pilsen, is very small and preserves only the Kladno-Pilsner beds which have an average thickness of about 100 meters; the succession is Barren sandstone, at most, 30 meters; shale with two coal seams, 40 to 45 meters; sandstone and conglomerate, very thin at times but occasionally reaching 60 meters. The Unterflötz is about 4 meters thick, but partings make the coal dirty; the few good layers are replaced with rock toward the middle of the basin. The Hauptflötz is 10 to 11 meters thick in the southern part of the basin. It is triple, but the middle bench alone is persistent; the lower is often replaced with rock and the upper thins away toward the northeast.

A petty area of anthracite coal is present near Budweis in southern Bohemia; it was studied by Katzer[41] soon after resumption of mining operations in 1890 and his results were published several years later. The exposed area of the deposits, believed by Katzer to be Permian, is barely 6 square miles. At the east and west the underlying rocks are Archean; at the north and the southwest, Tertiary beds overlie the Permian. There are two divisions; the lower consists essentially of conglomerate, sandstone and arkose; the upper has at base the coal group on which rest prevailingly red beds.

[41] F. Katzer, "Die Anthracit führende Permablagerung bei Budweis in Böhmen," *Oesterr. Zeitsch. f. Berg- und Hutt.,* Jahrg XLIII., 1895, sep. pp. 1–26.

The upper deposits show none of the regularity characterizing those of the lower division. The coal group consists of dark gray to almost black shale and sandstone, with thickness of not more than 20 meters. The seam of anthracite is from 80 to 120 centimeters thick; the dip at the important mine is toward north-northwest at abut 30° and there is little variation in thickness. The coal is clean anthracite throughout, except locally, where a thin black parting with some pyrite is found. The volatile varies from 6.2 to 6.8 per cent. and the ash from 6.4 to 9.4; complete analysis gives carbon, 88.90; hydrogen, 2.91; oxygen and nitrogen, 2.10; sulphur, 1.49; water, 1.80; ash, 2.80.

Dips vary from 1 to 45° and the whole district is much broken by faulting.

Germany.

Saxony.—The coal basins of Saxony, in the southern part of the kingdom are small, but the seams are often thick, yield good coal and are of great economic importance. The Zwickau and Lugau areas, known as the Erzgebirge basins, are at the southwest and the Döhlen (Plauenschen Grundes) is at a few miles away toward the norheast. Coal has been mined in some localities for centuries and the region has been studied by many geologists.[42]

The petty basins of Hainichen and Ebersdorf on northeastern border of the Carboniferous region hold deposits of Culm age. The lower division or Grundconglomerate has maximum thickness of 2,000 feet, but this decreases rapidly toward the south until the whole Culm is barely 1,700 feet, of which not more than one half belongs to the lower division. The coal-bearing or upper division, consisting mostly of sandstone, has four thin seams, which have been

[42] The works examined are H. B. Geinitz, "Die Steinkohlen Deutschlands und anderer Länder Europa's," Band I., 1865, pp. 45–90; H. Mietzsch, "Geologie der Kohlenlager," 1875, pp. 150–156; "Erlauterungen, etc., Blatt III., 1877; Th. Siegert, "Erlauterungen, etc., Th. Siegert, "Erlauterungen, etc., Das Steinkohlen-revier in Lugau-Oelsnitz," 1882; J. T. Sterzel, "Erlauterungen, etc., Section Stellberg-Lugau, Blatt 113"; "Palaeontologische Character des Steinkohlenformation und das Rothliegende von Zwickau," 2te Aufl., 1901; R. Hausse, "Steinkohlenbecken der Plauenschen Grundes (Döhlener Becken)," 1892; A. Dannenberg, "Geologie der Steinkohlenlager," Band I., 1908, pp. 199–224.

mined for local use. The coal is low in volatile and is said to be an excellent fuel.

The Coal Measures occupy depressions in gneiss, crystalline schists or in the older paleozoic rocks. The surface on which they were laid down was irregular and Lower Carboniferous is not always present. Within the Zwickau and Lugau areas, one finds the Saarbrück and the Lower Ottweiler, the Upper Ottweiler, if ever present, having been removed by erosion prior to deposition of the Rothliegende, which rest discordantly upon the Coal Measures. It is not easy to determine the boundary between Saarbrück and Ottweiler; Geinitz recognized three zones, marked by ***Sigillaria, Calamites,*** Ferns; later students, however, preferred to make only two, *Sigillaria* and Ferns, placing the limit about midway in the *Calamites* zone.

The Zwickau area is very small, not more than 20 square miles, but its coal seams are numerous and often very thick. These display in full all the peculiarities of limnic beds, variations in thickness, tendency to divide and to subdivide, frequent passage into shale and even into sandstone. The lowest persistent seam is the Planitz, which, at the southwest is practically single, but toward the northeast it is divided by increasing interval rocks and the three main benches become three seams, *A, B, C,* each of which has more than one local name. Near Planitz, the thickness is about 10 meters, the interval between *A* and *B* being less than half a meter; nearer Zwickau, the intervals are a half meter and two and a half; but, farther north, they become 40 and 15 to 30 meters respectively, the coal being 2, 4 and 4 meters in the several seams. The interval rocks are mostly sandstone. Toward the east and south, these seams are broken by so many partings as to be worthless, though they contain much good coal. In great part, the coal is bright Pechkohle, but it is often laminated or Schierferkohle and at times it passes into Russkohle, in which fusain (Faserkohle or Mineral Charcoal) predominates. The great Russkohlenflötz, at 40 to 56 meters above the Planitz, has an extreme thickness of 8 to 9 meters, almost wholly clean Russkohle. Toward the east and north, it breaks up into at least three seams, in which the Russkohle is often replaced with ordinary laminated coal. The coals of this lower

division, aside from the Russkohle portions, are, according to Mietzsch, coking. Geinitz states that the Planitz coal is of *Sigillaria* origin, while that of the Russkohlenflötz is derived from *Calamites.*

The higher zone has 7 seams of workable gas coal, 5 of which, one to three meters thick and yielding a caking gas coal, are practically exhausted. At best, their area was insignificant. The lowest two seams, Zach- and Schichtenkohlenflötz, are in larger area and each has a maximum thickness of somewhat more than 5 meters. Like the other seams, these divide and subdivide, the former toward the west and the latter toward the east. The total thickness of Coal Measures in the Erzebirge basins averages not far from 400 meters; that of the lower division, according to Mietzsch, varies from 40 meters in the southwestern portion to 80 and even 150 meters in the northeast, owing to inlaying of sandstones and conglomerates. The Rothliegende in these basins contains some worthless streaks of coal in the lower part.

The Döhlen basin or Becken des Plauenschen Grundes contains workable coal of Permian age, as determined in 1849 by Geinitz and Gutbier. Murchison[43] found the whole thickness of Lower and Middle Rothliegende between 800 and 900 feet. The conglomerates of the lower portion are gray, with blocks of granite, quartz and even of Coal Measures rocks. The coals are from Permian plants. These deposits, occupying a depression in Silurian rocks, consist of sandstones, conglomerates and shales, with, in the northern portion, a porphyry flow at the base. The color is mostly gray but variegated shale is present in the basal portion of the Middle Rothliegende. The coal seams are about midway in the Lower Rothliegende, within a mass of gray shale and sandstone, 20 to 30 meters thick. Geinitz mentioned four seams, of which the lower two are very thin. The third occasionally is thick but, for the most part, its coal is so dirty as to be almost worthless. The fourth or Hauptflötz is from 1 to 7 meters thick, the greatest thickness, as Haussė has shown, being in the deeper part of the basin; toward the border it becomes thin and impure. The partings are thin, but some of them are remarkably persistent. The coal is mostly laminated, but it often passes into Brandschiefer. The ash content is high, being,

[43] R. I. Murchison, "Siluria," 3d ed., 1859, p. 345.

according to Dannenberg, 18 to 32 per cent., selected specimens having as much as 22 per cent. The water is from 4 to 8 per cent. A thin coal seam is present in the basal portion of the Middle Rothliegende, but is without value.

In all areas, the Rothliegende is unconformable to the Coal Measures. Fragments of Coal Measures rocks are common in the basal conglomerate and Siegert saw in the Lugau area large blocks of coal torn from exposed coal seams. Grains of coal occur commonly.

In 1881, Sterzel discussed the origin of coal seams and in 1901 a revised edition of his paper was published. He sums up in thoroughly judicial manner the features which, for him, appear to suggest autochthonous origin of the materials, and then presents the features which indicate allochthonous origin. These are:

(*a*) The often very distinct lamination of the coal; (*b*) the Bergmittel, which at times occurs abundantly within coal seams and consists of the same rock material as the Hangende and Liegende of the seam, is evidence of quiet deposition, as must be accepted for the plant material itself. Bergmittel may be in form of increased ash in the coal, or as conformable deposits, plates or benches of clay shale, or iron ore, varying in extent and often splitting the coal bed into an extraordinary number of thin plates. A new vegetation for each of these many thin coal layers appears inadmissable; (*c*) Stigmaria occurs frequently in the roof; (*d*) vertical stems in the roof of beds are only local and occasional. He concludes that the majority of facts speak for allochthonous origin of the Zwickau coal seams.

All observations lead him to the belief that the coal seams were formed in a lake basin, into which the plant material was carried from the widely extending swampy surrounding land, which was fitted for Waldmoors with luxuriant vegetation, as well as from the higher slopes, on which were plants, loving a drier region. The infloating was done by quiet waters, which carried very little inorganic matter. Plant materials predominated, so that great masses of more or less rotted organic matter were heaped up on the lake bottom, where afterward they were converted into coal. Occasionally, the watercourses were swollen and brought down rock material, which

formed partings, to be covered in succeeding time of quiet by a new deposit of plant stuff.

Periodically, perhaps because of crustal movements, notable changes came about in the fall of streams, leading to violent floodings. Then rock materials predominated and deposits of sand, mud and pebbles were formed, covering the plant materials, which are now the coal beds. Later came the period of quiet and the Waldmoor expanded to its former luxuriance. During the interval, many species of plants had been destroyed while others survived and new forms appeared. This doctrine of local change does not exclude changes in the lake bottom; that might be brought to a higher level, so that growth of plants might begin on it. Increased accumulation of detrital material in the lake would have the same effect. Perhaps, in some places of this sort, there grew the vertical stems, giving a local autochthonous formation.

Sterzel's conception closely resembles that presented by Grand-'Eury in 1882, which was abandoned by that observer after his knowledge had been increased by careful studies in regions aside from his own basin of St. Etienne. But the presentation is far from being conclusive.

Lamination of coal is by no means evidence that the material was transported; autochthonous peat, subjected to pressure, has the same structure. *Sigillaria* and *Lepidodendron* occur in roofs of coal seams; as *Stigmaria* is the rhizome of those plants, it ought to occur in roofs. Partings, such as those of coal seams, are familiar features of autochthonous peat deposits. Vertical stems are apparently rare and local in roofs, but there are vast areas of growing peat without trees, while there are other areas in which the Waldmoor condition prevails. It must not be forgotten that our knowledge of roofs is confined chiefly to exposures in mines, where the stems are only too abundant.

There is not much basis for the suggestion that a great lowland area, covered with Waldmoor, was the region surrounding the Zwickau lake. The Erzgebirge had been elevated prior to Carboniferous time and the Zwickau basin is at the foot of those mountains. Even if there had been a great Waldmoor area, it is inconceivable that streams meandering across it could bring down such great quan-

tities of macerated vegetable material. The density of vegetation in a Carboniferous Waldmoor was not inferior to that of a tropical jungle. Rain would have practically no erect on even loose plant stuff, while the meandering streams would remove little from their banks. Every one knows that such streams have great plumes of confervæ swinging from the banks, undisturbed year after year. It is difficult to conceive of crustal movements so abrupt as to cause floods, so sudden and severe as to sweep débris over the plain, to destroy the great Waldmoor and to leave no trace of the dense vegetation in the newly deposited rocks. It is equally difficult to understand why crustal movements should increase the water-supply. They would lead to rapid draining of the region but could not bring about terrific floods unless the rainfall were increased many times. In any event the floods would be mere floods, not devastating torrents, unless the Waldmoor area itself were distorted, in which case it would not be available for a new Waldmoor.

In 1903,[44] Sterzel described a *Sigillaria* stump, seen in the roof of the Zachkohenflötz. It was 1.25 meter high and tapered from 1.15 at base to 0.50 meter at top. The base was completely plane and the border was sharp. There is no trace of branching or of *Stigmaria,* as there should be if the plant were in place of growth. The stem evidently had been torn from its place by muddy water, robbed of its basal branching and then deposited in the roof of the coal seam. The softened base had become flattened under pressure. He states that the limit between coal and roof is "haarscharf" and that nowhere does the plant rise out of the coal into the roof. Sterzel's description shows that here is the familiar "Sargdeckel." The region is disturbed, the contact between coal and roof is sharp, neither is in its original relation to the other. The faulting explains the smooth base of the stump. Such stumps are not rare in roofs of the Zachflötz and Segen-Gottesflötz of Zwickau area.

Sterzel,[45] in a later paper, described a petrified forest observed in the Rothliegende of the Chemnitz region. The rich locality, near

[44] J. T. Sterzel, "Mitteilungen aus der Naturwiss.-Samlung der Stadt-Chemnitz," *Ber. Naturwiss. Gesells. Chemnitz,* t. XV., 1903, Separate.

[45] "Der versteinerte Wald," etc., the same, Band XVIII., 1913, Separate, p. 52.

Neuhilbersdorf, embraces about a square kilometer. The ground is full of petrified trees; beside prostrate, always fractured stems, large and small stems are seen as vertical stumps, apparently in the original place of growth. Silicified stems are shown at several places near Chemnitz. They are embedded in the marly beds of the Middle Rothliegende, on which, apparently, they grew.

He cannot accept the opinion that the trees while living were enveloped suddenly by the falling tuff and that they were silicified afterward. The plants are without bark and are broken across the stems. He believes that silification began during life of the trees and that it caused their death. The microscopic structure is as perfect as in living plants. All are conifers—*Araucarioxylon,* to which the leaves and twigs of *Walchia* seem to belong. Stems, 7, 10 and 20 meters long, are in the Chemnitz museum.

Thuringer Wald.—The Permian contains coal seams of workable thickness at several localities in Germany. For the most part, they have little interest, but the conditions in the Thuringian forest should be noticed. This area, bordering on Bavaria at the south, was visited several times by Murchison,[46] who states that in some valleys on each side of the Central Range there occur occasional outcrops of gray and dark colored shaly rocks, containing plant remains and at times seams of coal. These he regarded as belonging to the Upper Coal Measures of Germany. The coal is most abundant at the southerly end of the area, where it has been reached by shafts, which pass through a great thickness of Rothliegende. These Carboniferous beds were formed, he believes, during tranquil deposition, in marked contrast with the Permian beds, which were laid down during a time of great disturbance, marked by extrusion of much igneous material and by powerful translation of broken materials from preëxisting rocks. The coal-bearing deposits pass under cover toward the north.

Beyschlag,[47] writing many years afterward, stated that study of the central portion of the region is difficult as no good section is exposed. Eruptive rocks are abundant and sedimentary rocks

[46] R. I. Murchison, "Siluria," 3d ed., 1859, p. 332.

[47] Beyschlag, "Geologische Uebersichkarte des Thuringer Walden," *Zeitschr. d. d. Geol. Gesells,* Band 47, 1895, pp.. 596–607.

change abruptly in character as well as in thickness. Conglomerates prevail at the southeast, but in the middle and northwest portions the rocks are chiefly sandstones and shales. He assigns the whole section to Rothliegende, there being no Upper Coal Measures in the region. The succession is:

Upper	Tambacher beds	
Middle	Oberhofer beds	Lebacher beds
	Goldbauter beds	
Lower	Mansbacher beds	Cuseler beds
	Gehrener beds	

The Gehrener beds contain much eruptive matter and arkose; red and black shale with gray sandstone and breccia prevail; coal smuts and seams were seen near Gehren and a few other localities. The Mansbacher beds have no eruptives, the rocks being sandstone and clay shale with some thin seams of coal. At one time, six of these seams were mined. The flora of these shales was supposed to be that of the Upper Ottweiler (Stephanien), but it is predominantly Rothliegende, though containing many Ottweiler forms. *Walchia* occurs in sandy clay shale but never in the softer, plant-rich shales. The Goldbauter beds have much eruptive material in the western portion but none in the eastern. Midway in the section is a thin seam of coal. This is the highest, there being no coal in the Oberhofer or Tambacher beds.

Dannenberg[48] cites v. Dechen as stating that coal occurs in the Middle and Lower Rothliegende. The important locality is on the Bavarian border near Stockheim and Neuhaus, where a seam, 2.90 to 29 meters thick, is mined. When very thick, the coal is notably dirty, but washing removes most of the impurities and the coal, thus treated, is an excellent fuel. The output of washed coal in 1911 was 50,000 tons and plans were under way to increase it to 240,000.

The Pfalz-Saarbrück-Lorraine Coal Field.—This, known as the Saarbrück basin, is comparatively insignificant in area but is amazingly rich in the number and availability of its coal seams. The space, in which seams are exposed or under reasonably thin cover, is

[48] Geologie der Steinkohlenlager, p. 229.

rudely triangular, about 20 kilometers wide on the Saar River and diminishing northeastwardly to 10 kilometers at a little way beyond Neukirchen, 50 kilometers from the Saar. The extreme distance, along which the coal is accessible, is barely 100 kilometers, extending from beyond the eastern border of Lorraine across the narrow strip of Prussia into the Rheinpfalz of Bavaria. The field has been described more or less in detail by many students, but use will be made here only of works by Nasse,[49] v. Ammon and Dannenberg. Nasse and Dannenberg have discussed the whole basin, while v. Ammon has described in detail the Bavarian field, which embraces the greater part of the available area.

The deposits occupy a trough, much distorted, which is cut off abruptly at the south by the südliche Hauptsprung, a downthrow of not less than 1,000 meters. Only Permian and Carboniferous rocks have been found within the trough, but Bunter Sandstein is present just beyond the immediate area. The lowest beds reached by borings are Saarbrückian, which are succeeded by Ottweiler and Rothliegende in conformable order, so that the whole may be termed the Permo-Carboniferous system; but in the extreme western portion, within France, there is unconformity, for there Rothliegende rests on disturbed Saarbrückian beds. The latest classification is Rothliegende, Upper, in four divisions, of which the Lebacher beds are

the lowest. This contains plants, Estheria, reptiles, fishes and worthless streaks of coal. Lower, the Kuseler beds, containing similar fossils, some calcareous beds and streaks of coal.

Upper Carboniferous,

Ottweiler beds. Upper, containing fish remains, etc., with Breitenbach coal bed. Middle, or Potzburg beds, with some calcareous beds, *Leaia, Cardinia* and the Hirteler coal seams. Lower, the Hangende Flötzzug, fossils as in Middle; Holzer Conglomerate at base.

Saarbrück beds. Upper or Flammekohlen Gruppe, Lower or Fettkohlen Gruppe.

[49] R. Nasse, "Geologische Skizze des Saarbrücker Steinkohlengebirge," *Zeitsch. Berg-hutten-Salinen-wescn im Preuss.*, Band 32, 1884, Abh., pp. 1–89; L. v. Ammon, "Die Steinkohlenformation in den Bayerischen Rheinfalz," München, 1903, pp. 1–106; A. Dannenberg, "Geologie der Steinkohlenlager," pp. 105–165.

Lower deposits are unknown and it is uncertain whether or not the Waldenberg (Sudetic, Lower Westphalian) and Lower Carboniferous are present. The rocks are of limnic origin; no marine forms have been observed.

Dannenberg gives the thickness of Rothliegende as not less than 2,000 meters, that of Ottweiler as 1,500 to 2,000 and of Saarbrück as 2,500 to 3,000 meters. Nasse estimated that Ottweiler is 1,700 to 2,000 in the area between Saar and Blies Rivers, but 3,000 in the eastern portion within Bavaria; the Saarbrück, on the contrary, become thinner toward the east, being 3,200 on the Saar but only 2,100 on the Nahe River. Borings in later years have proved that, while it is true that Ottweiler increases notably toward the east and that Saarbrück decreases notably in that direction, the variations are not so great as Nasse believed. It is very clear that influx of material for Saarbrück was from the west and for Ottweiler from the east, the coarse deposits for the latter being on the east side, while in the former they are on the west side.

The number of coal seams, according to Dannenberg, is not far from 400, of which 150 to 160 are workable, that is to say, are more than half a meter thick. Nasse showed that these are grouped into "Flötzzuge," separated by practically barren intervals. The coal seams of the Rothliegende and Ottweiler are not important and only insignificant seams were formed above the Kuseler beds. There were serious extrusions of igneous rocks in the earlier Saarbrück and in the closing portion of the Upper Rothliegende.

Thin coal is present in the Lebacher beds, which are mostly yellow sandstone and dark shales; in the western portion, the shales have fish remains and iron ore, but the ore is wanting at the east. The flora, according to Nasse, consists almost wholly of Rothliegende forms, with very few of Coal Measures type. The Upper Kuseler rocks are mostly gray shales and sandstones; coal seams were observed at many places; one, the Kalk-kohlen Flötz, has a limestone roof and occasionally becomes 47 centimeters thick; another, near the base, the Muschel-kohlen Flötz, is from 15 to 20 centimeters thick and its shale roof has abundant *Anthracosia.* The Lower Kuseler consists chiefly of gray and red sandstones, variegated shale and thin layers of limestone. Fish remains have been

obtained at several horizons and the flora is rich in Rothliegende forms, among them, *Callipteris conferta*. With these are many Coal Measures species, but no *Sigillaria* or *Stigmaria*.

The Upper Ottweiler, about 125 meters thick, has mostly grayish deposits, laminated shales and micaceous sandstones. In Bavaria, it has the Breitenbacher or Hausbrandflötz, 12 to 30 centimeters thick, which is mined by stripping at many places, as the coal is an excellent domestic fuel, being maigre, smokeless and without clinker. The flora is mingled Saarbrück and Rothliegende; Weiss, quoted by v. Ammon, has described it as a "prevailingly stone-coal flora; *Stigmaria, Sigillaria* and *Lomatophloios* still abundant, ferns numerous, *Walchia* rare." Animal remains are few, chiefly insects and crustaceans. The Middle Ottweiler is a thick complex of mostly red sandstone and conglomerate, with red, bluish and yellow shales. The conglomerates, according to Nasse, are not constant but are lenses. The Hirteler coal seams are unknown in Bavaria but are present near Saarbrück in Prussia. Fossil plants are not abundant and such as do occur are indefinite, but silicified wood is not rare. v. Ammon states that the mass is 800 meters thick near Saarbrück, but near Dudweiler in Bavaria it is 950. The Lower Ottweiler, formerly regarded as Upper Saarbrück, about 800 meters in western part of the basin, contains much red rock, gray, reddish and greenish shades and sandstones. Its base is the Holzer conglomerate, which is characteristic at the east but becomes insignificant toward the west. Over it are the *Leaia* shales, which enclose thin layers of limestone and underlie the Hangenden Flötzug, consisting of gray and some red sandstone and shale with two or three variable seams of coal. The thicker seams, Lummerschieder and Walschieder, are of workable thickness in the Prussian area but become insignificant or disappear toward the east in Bavaria. At Frankenholz, 5 coal streaks were found but at Dittweiler, farther east, no trace of coal was found in the boring. The thickness in the Prussian area is not far from 1,000 meters and is considerably more in Bavaria.

The Saarbrück is divided into the Upper or Flammekohlengruppe, yielding a sintering coal, and the Lower or Fettkohlengruppe, from which coking coal is obtained. Conglomerates are numerous, especially in the western portion, where, according to

Nasse, there are beds more than 40 meters thick. The pebbles are mostly of quartz but other rocks are represented. The shales are gray to blackish, but some beds are red or green. The flora, according to Weiss, cited by v. Ammon, is a "Steinkohlen flora, with many *Sigillaria* and lycopods as well as ferns." v. Ammon states that *Walchia pinniformis,* characteristic of the Lower Rothliegende, occurs sporadically. The Schatzler beds of the Lower Silesian basin have a flora like that of the Lower Saarbrück.

Within Bavaria, the Upper Saarbrück coals are mined at Frankenholz and Consolidated Nordfeld, both in the eastern portion. The group is divided into Upper and Lower, the former being worked at places named. Twenty-five coal seams have been discovered, of which more than half yield a gas coal while the others have Flammekohle. The screenings of each are mixed with Fettkohle in manufacture of coke. The seams show great variation within Bavaria; several, which are important at some localities, become unworkable or disappear within short distances. The seams become thicker toward the west. Kliver, cited by Dannenberg, states that at or near Jaegersfreude there are 10 workable seams, 21 which are too thin for working under present conditions and 101 which are mere streaks; in all, 132 with 32 to 33 meters of coal. Some seams are from 3 to 5 meters thick, but they are broken by partings into several benches. The lower division is less important, having only 3 or 4 workable seams, though the whole number of seams is about 40. At one time it was believed that this division thinned away toward the east, but this opinion has not been confirmed by the later observations.

The Lower Saarbrück or Fettkohlenpartie yields coking and gas coals. The number of seams and the coal content increase from east to west. This division is mined in the Pfalz region within the St. Ingbert and Mittelbexbach areas, where three groups of coal seams exist. The upper, about 537 meters thick, has 40 seams; a barren space of 63 meters separates it from the middle or Rothhell, 240 meters thick and containing 19 seams; at probably 300 meters lower is the bottom group, discovered in a boring within the Rischbach Valley, which has 12 thin seams. The rocks of Lower Saarbrück are coarse, there being much sandstone and conglomerate.

The coals of the highest group vary from Fettkohle to Flammekohle; a single seam may yield both kinds. The Rothhell consists of gray shales, hard sandstones and conglomerates with an occasional red bed. The coals are important at St. Ingebert, but westwardly they decrease and are insignificant at the Saar River. The Rischbach seams appear to be merely local, having been found only in a boring and a shaft within the Rischbach Valley.

In the Mittelbexbach area, 10 seams with 9 meters of coal are mined. They belong to the highest group and yield only Flammekohle, which is an admirable domestic fuel. The mines are near the südliche Hauptsprung, where the strata are seriously disturbed. The seam, Number 3, has an interesting structure in one mine. It consists of coal, 0.04; parting, 0.20; coal, 1.20. The thin bench on top is much broken by overthrust faults, which involve the parting, but the main coal is practically undisturbed. This upper group of the Lower Saarbrück becomes extremely important in the vicinity of Saar River, where there are 40 workable seams with 50 to 60 meters of coal. Cannel is present occasionally but it is unimportant. At one place it is the highest bench; at another it is the lowest.

Nasse, in discussing the character of coal seams, states that in this basin a seam one meter thick is rarely without partings, but he mentions one, 4.08 meters, which yields clean coal throughout. Variation in thickness is the rule; mere streaks become important seams, which may thin away to disappearance. The intervals are uncertain, so that seams widely separated at one locality may be united at another. Very often the roof is Brandschiefer, a coaly shale, which is combustible. When sandstone or conglomerate is the roof, the upper part of the seam is irregular; but the bottom rarely shares in this irregularity.

The Ruhr Basin.—Several coal basins are in northwestern Prussia, which are of moderate extent but, in some cases, economically important. The Ruhr, Lower Rhine or Westphalian basin lies east from the Rhine along the Ruhr, Emscher and Lippe Rivers; the cities of Essen, Bochum and Dortmund are on the northern border. The area is not far from 3,200 square kilometers, but the thickness and quality of coal render it one of the most important on the continent. The outcropping portion is south from the cities mentioned,

but borings prove that the coals persist northward beyond the Lippe under increasing cover and that, in like manner, they are present west from the Rhine. The region has been studied carefully by Dannenberg,[50] who has supplemented his observations by those of other geologists.

The Lower Carboniferous (Dinantien) is shown on the eastern border, where it is succeeded by the Flötzleeren Sandstein (Namurien or Lower Westphalian), which apparently is without coal and is taken to be the equivalent of the Millstone Grit, the Sudetic of eastern areas. This is followed by the Productive Coal Measures, equivalent to Saarbrück (Upper Westphalian), as well as to the Lower and Middle Coal Measures of Great Britain. It is the important group. The Ottweiler, Stephanien of France, is apparently absent. Permian is represented almost wholly by the Zechstein, Rothliegende having been observed in only a few petty, isolated patches. The Saarbrück is in four divisions, which, in descending order, are:

	Volatile.	Chief Seam.	Thickness.
Gasflammekohlen	37–45	Bismarck	1,000 m.+
Gaskohlen	33–37	Catharina	290–300 m.
Fett- and Esskohlen	20–33	Sonnenschein	600–885 m.
Magerkohlen	5–20	Mausegatt	1,050 m.

There are variations in the conditions for, chemically, the coal of a seam is not the same throughout its extent. Beds of the Magerkohlengruppe at times yield coking coal; among the Fettkohlengruppe, some give gas coal while coking coal is obtained from several seams in the Gaskohlengruppe. Generally speaking, the volatile content increases from west toward east, as does the thickness of the seams. Conglomerate and ironstone are common in the Magerkohlen, less so in the middle divisions, but are abundant in the upper. Marine deposits are frequent in the lowest division, but become fewer above, where fresh-water fossils are the usual forms.

The Magerkohlengruppe is practically barren in the lower 250 to 300 meters, there being only thin seams, some of which are workable locally. The next portion, reaching to the Hauptflötz, has at

[50] A. Dannenberg, "Geologie der Steinkohlenlager," 1908, pp. 49–79.

least two workable seams and is 100 meters thick. The Hauptflötz and the Wasserbank, 80 meters lower, have well-marked marine roofs; between the Hauptflötz and the Mausegatt, 250 to 300 meters, coal seams are few and but locally workable; the Sarsbank, about midway, has a marine roof. The next interval, 100 to 150 meters, has four or five workable seams with 3 to 4 meters of coal and contains much iron ore, which was mined in earlier days. It has three beds with fresh-water fossils. The highest interval, about 300 meters, is almost barren, having few and rarely workable seams. The most notable feature is the rich marine roof of the seam Finefrau-Nebenbank near the base of the interval. This Gruppe ends with a well-marked conglomerate, 10 to 20 meters thick.

The Fettkohlengruppe, from the Sonnenschein to the Catharina, averages about 600 meters, but the mass increases toward the east, coal increasing in the same direction from 23.6 to 35.85 meters. Clay shales predominate, sandstone is rare and conglomerate is unknown. Ess- or Schmiedekohle, with about 20 per cent. of volatile, predominates in the lower part, but in the upper part the volatile becomes 33 per cent. and the coal is caking. The coal seams tend to divide, detracting from their value. Catharina alone is easily identified in a considerable area, as it has a marine roof.

Changes in most of the seams are so abrupt that tracing is impossible; mere smuts suddenly become workable seams and as suddenly become worthless again.

The Gaskohlenpartie is almost barren in the lower half, but the upper portion has about 10 workable seams with 8 meters of coal. The lower part has a seam of cannel, 47 centimeters thick. Changes in chemical composition of coal in individual seams are frequent. No marine forms have been discovered except at the very base, in the roof of Catharina.

The Gasflammekohlengruppe has 25 seams more than 50 centimeters thick. Clay shales predominate in the lower half and the coal seams are much less variable than those in the upper half, where sandstone and conglomerate prevail. Chemically, the coal varies notably; in extensive districts, only gas coal is found. Cannel occurs frequently; one seam has 1.36 m. as the upper bench and 1.37 m. as the lower.

There is every reason to believe that the Ruhr basin is continuous under cover with the Aachen basins at the west; it may be continuous also with the Limbourg area of Holland and the Campine area of Belgium, in both of which the coal is deeply buried and its existence has been proved by borings.

The Aachen Basins.—These, often referred to as the Westphalian basin, embrace, according to Dannenberg,[51] two areas, the Würm- (or Worm-) Revier, north from Aachen, separated by a strip of Upper Devonian from the Stollberg-Eschweiler Revier, southward from that city. The latter is known also as the Inde-Becken.

The Würmrevier, locality of oldest coal mining operations on the Continent, has not less than 45 coal seams in the western portion, of which 11 have been exhausted. Of the others, 14 are workable with 12.5 meters of coal, the lowest being the Steinknipp, about one meter thick. The disturbance in this portion was extreme and the coal is in great part anthracitic. Dannenberg notes that these coals are at horizons, which, in the Inde basin, have coals much richer in volatile. He suggests that the change was not due to disturbance alone but possibly in part to lack of thick cover. In the eastern portion, where disturbance, though severe, is less than in the western, one finds coking coal with 16 to 24 per cent. of volatile, and non-coking coal with 15 to 17 per cent. The remarkable horizon is the marine roof of Bed 6 at the Marie mine. The Flötzleeren Sandstein has not been recognized in this area.

The Inde-becken or Eschweiler revier has the succession complete from Lower Carboniferous to and including the Saarbrück. The boundary between Lower Corboniferous and Coal Measures is sharp, there being no passage beds between the limestone below and the sedimentary rocks above; yet there appears to be complete conformity. A mass, almost wholly sandstone and 800 to 1,000 meters thick, rests on the limestone. This, practically barren, as it contains only two or three unworkable seams of coal at 150 to 200 meters above the base, seems to be equivalent to the Millstone Grit. The Productive Coal Measures, somewhat thicker than the barren measures below, have two groups of coal seams, the Aussenwerke and

[51] A Dannenberg, "Geologie der Steinkohlenlager," pp. 83–101.

the Binnenwerke, separated by an almost barren interval of several hundred feet. The relations of the lower group, the Aussenwerke, cannot be determined satisfactorily owing to lack of distinct flora and fauna; it may be equivalent to the lower division of Würm, in which a marine deposit is roof of Marie number 6. But the Binnenwerke is unquestionably Saarbrückian or Upper Westphalian. Forty-five coal seams have been recognized, none of them thick. In the western portion of the workable seams, only 2 ever exceed 1 meter, 5 never exceed 75 centimeters and 9 are less than 60 centimeters. The Aussenwerke seams are thin.

The disturbance is much greater in the eastern part of this basin than in the western, but the coals are same, chemically, in both. Binnenwerke coals are caking and their coke is good, but that from the Aussenwerke is sintering. Five conglomerates are persistent; two of them, thick and coarse, are in the Flötzleere, above and below the coal seams; the third is just below the Aussenwerke and is an important stratigraphical horizon; the fourth is just above that division and the fifth, comparatively fine-grained, underlies the Padtkohl or lowest seam of the Binnenwerke.

Belgium and Northern France.

Some prongs of the Aachen Coal Measures reach into Belgium, but exposures end quickly and a space of about 20 kilometers, covered by later deposits, intervenes between the last Aachen outcrop and the first Belgian mines. Within Belgium, Coal Measures remain in the Dinant trough, at the south, but the basins are isolated, very small and without interest. At the north is the extensive Campine area, continuous with that of Limbourg in Holland, but that is known mainly through records of boring, as mining operations were begun very recently. Actual work is confined to the great Haine-Sambre-Meuse trough, which extends from the Prussian border across Belgium into the Department du Nord of France; it is interrupted only by a narrow barren space in the Samson Valley, which divides the Belgian area into the Liége basin at the east, including the Herve, Liége and Andenne districts, and the Hainaut basin at the west, embracing the Basse-Sambre, Charleroi, Centre and Couchant-de-Mons districts.

The succession in Belgium is sufficiently clear, though, owing to the extreme distortion along the southern border, some localities remain, in which relations are somewhat uncertain. The order as given by Renier is

Stephanien	Absent	
Westphalien	Supérieur	Assise de Flénu (Renier)
		Petit-Buisson
		Assise de Charleroi (Stainier)
		Gros-Pierre = Stenaye
		Assise de Chatelet (Stainier)
		Poudingue houiller
	Inférieur	Assise d'Andenne (Stainier)
		Veine aux Terres
		Assise de Chokier (d'Omalius)

Dinantien or Lower Carboniferous.

This is equivalent to the grouping presented by de Lapparent and Munier-Chalmas. Stainier prefers to limit the term Westphalien to the upper three assises and to apply the name Namurien to the lower part of the section. This nomenclature has been accepted by Dannenberg in his description of the Belgian fields. The coal seams, Petit-Buisson, Gros-Pierre and Veine-au-Terres are at or very near the base of the several assises. The number of marine horizons decreases upward; it has been suggested that some relation may exist between quality of coal and the origin of the rocks; Chokier, essentially marine, is wholly barren; Andenne has marine horizons and little coal, which is true also of Chatelet; but Charleroi, without positively marine deposits, is rich in coal; Flénu has but one marine deposit, that in roof of Petit-Buisson at the base, and this assise has much coal.[52]

Formerly, the Coal Measures were divided into H1, *a, b, c,* and H2, the former being the Namurien, the latter being the Westphalien or upper Westphalien. The general features of the lower division were described by Purves.[53] The Chokier, or basal assise, is a mass

[52] These details are mostly from A. Renier, "Les gisements houillers de la Belgique," *Ann. Mines de Belg.*, t. XVIII., 1913, pp. 757, 759, 767, 773.

[53] J. C. Purves, "Sur le delimination, etc., de l'étage houiller inférieur de la Belgique," *Bull. Acad. Roy. Belg.*, III., t. II., 1881, sep., pp. 1–57.

of shale, 10 to 70 meters thick, increasing toward the west. The middle portion, the Andenne of Stainier, is 130 to 400 meters, increasing, as the Chokier, toward the west. It has thin streaks of terroulle or earthy coal, one of which, near the base, has been mined; it has a sandstone roof containing *Calamites* and is 40 centimeters thick; it has a true underclay, with *Stigmaria*. A persistent band of ripple-marked sandstone, 5 to 10 meters thick, overlies the coal-bearing shales and a marine deposit is near the top of this division. The Grés grossier, or Poudingue houiller, the Poudingue de Monceau-sur-Sambre of Mourlon,[54] at top of the Namurien, 12 or more meters thick, varies from fine sand to coarse conglomerate.

Dannenberg says[55] that in the Liége district the Andenne has three seams, of which the middle one, V. au Gres, is the best; that at the base, V. aux Terres, is so dirty as to be worthless. Stainier[56] states that, in the Andanne or eastern district of the Liége basin, the Chokier consists chiefly of dark laminated shale, utilized in manufacture of alum. The Andenne, mostly shale, has the lowest coal seam at 80 to 130 feet meters above the Lower Carboniferous limestone. It is thin, without value, and underlies a sandstone, often 20 meters thick. On this rests a mass of shales containing the only workable seam, known as Plateur-de-Rouvroy, Pélémont, Six-Mai and Grande Veine, which at times is one meter thick, though usually between 50 and 60 centimeters. It is terroulle, an intimate mixture of coal and clay, burning slowly and without flame. Almost invariably it is in two benches, one giving fine, the other lump coal. At the western extremity of the district, this seam divides, but the benches retain their character. The roof is marine in the eastern portion, containing *Lingula* and *Loxonema*. The poudingue houiller has beds of conglomerate with pebbles, at times, of one decimeter diameter; it would seem that these conglomerate layers are merely lenses.

Smeysters[57] notes that, in the eastern part of the Hainaut basin, the lower Westphalian has an extreme thickness of 350 meters, but

[54] M. Mourlon, "Géologie de la Belgique," 1880, t. I. p. 119.

[55] Geologie der Steinkohlenlager," p. 280.

[56] X. Stainier, "Bassin houiller d'Andenne," *Bull. Soc. Belg. de Geol.*, t. VIII., 1894, Mem., p. 3–22.

[57] J. Smeysters, *Ann. Mines de Belg.*, t. V., 1900, pp. 1–128.

it decreases toward the east, becoming only 150 beyond Namur. Three coal seams are in the middle stage (Andenne), all of which are mined locally in the eastern part of the basin. *Calamites* and *Stigmaria* are abundant. A thin coal seam near the top has a marine roof. Conglomerate is of only sporadic occurrence in the Poudingue houiller.

Stainier,[58] in the Charleroi and Basse Sambre districts, found the equivalent of the Andenne Plateur-de-Rouvroy in the Veine du Calvaire, which is 50 to 60 centimeters thick; it has been mined for many years. This bed is at 110 meters below the Poudingue. The lowest seam, Fort d'Orange, is half a meter thick and yields an excellent coal of the terroulle type, its composition being: volatile, 10.5; fixed carbon, 84.34; ash, 5.16. The coal seams are all very thin in Charleroi and a similar condition exists in Couchant de Mons. Cornet[59] has shown that the Chokier fauna in the latter district is wholly marine, but of littoral type. The deposits are fine-grained, but he shows that this is no proof of deep water, for the great proportion of the forms are mollusks with byssus. Seventy per cent. of the Coal Measures deposits are fine material. He is convinced that lowland surrounded the area of deposition.

The Westphalian (Upper Westphalian) has, in ascending order, the assises of Chatelet, Charleroi and Flénu.

The Chatelet is poor in coal and the seams are thin, though less irregular than those of the Andenne. In the Liége district, two seams are worked, Chesson and Grande Pucelle or Désirée, 70 and 60 centimeters thick.[60] The former has a marine roof, which Dannenberg believes equivalent to that of Ste.-Barbe-de-Floriffoux in Charleroi district and very probably to that of Breitgang in Eschweiler, Finefrau-Nebenbank in Ruhr. The coal of Grande Pucelle has 16 per cent. of volatile at the south, but only 6 per cent. in the northern, the less disturbed portion of the district. Very little of the Chatelet remains in the Andenne district and but one seam is mined. This, the Chenevis, at 120 to 160 feet above the poudingue

[58] X. Stainier, "Stratigraphic, etc., de Charleroi et de la Basse-Sambre," *Bull. Soc. Belg. de Geol.*, t. XV., 1901, Mem., pp. 1–60.

[59] J. Cornet, "Le terrain houiller sans houille (H1 *a*)," *Ann. Soc. Geol. de Belg.*, t. 33, 1906, Mem., pp. 139–152.

[60] A. Dannenberg, op. cit., p. 280.

houiller, has a typical mur and the toit is rich in plant remains. Stainier[61] thinks that the poverty of the Chatelet in the Hainaut basin is remarkable, there being only one generally workable seam, though some veinettes are mined locally. The V. Leopold. known under many names, is 100 to 140 meters above the poudingue and attains workable thickness at numerous places. At 50 meters higher is the V. Ste.-Barbe-de-Floriffoux, which is thickest midway in the basin, where it is in two benches, 10 and 40 centimeters, separated by a shale parting of 80 centimeters, and yields a coal having volatile, 17; fixed carbon, 68.72; ash, 14.28. The mur is white, silicious, with *Stigmaria,* and is from 0.30 to 1 meter thick. It bears great resemblance to the English ganister. The roof is black laminated shale with marine fossils. Stainier has described at least six horizons of fossils, one of them unmistakably marine, the others probably brackish water. The Chatelet coal seams become wholly unimportant toward the west.

The Assise de Charleroi is divided in the Liége district into St.-Gilles, Liége and Seraing faisceaux, 200, 350 and 400 meters as extreme thicknesses. The coal seams are 9, 14 and 13. All are thin, rarely reaching one meter, but the Grande Maret, at base of the Liége faisceau, averages 1.80 and sometimes reaches 2.12 meters; it has three partings, 77 centimeters, and is the only seam in this faisceau which is mined systematically; the Grand Bac, next above it, is mined at some localities. Only two seams of the Seraing, the Stenaye at base and the Houilleux next above, are worked; but these are exceedingly variable. The marked marine horizon in roof of Grand Bac is thought by Dannenberg[62] to be equivalent to that over Coal 6 of Mine Marie in the Aachen and that of Catharina in the Ruhr basin. He correlates Charleroi with Saarbrückian.

Charleroi deposits have been removed from the Andenne district but they are important in the Hainaut basin. Stainier finds three faisceaux, Sablonniére, des Ardennoises and Goufre. The upper part of the Sablonniére is no longer accessible, but there are six workable seams and several streaks in the lower portion. Almost all of them have a faux-toit, sometimes cannel-like, and are divided

[61] X. Stainier, *Bull. Soc. Belg. Geol.,* t. VIII., 1894, pp. 17, 20.

[62] A. Dannenberg, op. cit., p. 284.

into benches. The lowest seam, like Ste.-Barbe-de-Floriffoux, has the *en chapelet* structure and shows extraordinary changes in thickness. The middle faisceau has 16 seams, 0.45 to 1 meter thick, many of which have a faux-toit of gallet, or of shale and coal, and a typical mur. The roof in some cases contains *Naiadites* and *Carbonicola*. One seam has *en chapelet* structure; intervals between seams vary, apparently without rule. The Goufre or lowest faisceau is the most important, having 10 workable seams, 4 of them more than 1 meter thick, and all more regular than those of des Ardennoises. The highest seam, V. Anthracite, is often absent, having been removed during deposition of the overlying sandstone, which occasionally reaches almost to the V. Caillette, 3 meters below. V. Anthracite is seldom thicker than 30 centimeters and its coal has but 8.80 per cent. of volatile, much less than that in any seam below it. The V. Tatonie has sandstone pebbles and is very close to the underlying Grés de Hamm, which is 10 to 12 meters thick and closely resembles the poudingue houiller; like that, it contains grains and pebbles of bright coal. The thickest seam, Dix-Paumes, has 1.28 meter of coal on the north and south sides of the basin, but is much thinner midway. It contains pebbles of quartzite and fragments of gallet, a cannel-like shale. The coal is excellent, with 16.1 per cent. of volatile and only 3.5 of ash. V. Gros-Pierre, Stenaye of the Liége district, is irregular, usually present at the east but disappearing toward the west. It has, at most, 0.93 of coal in 4 benches; its coal has a fibrous structure and frequently contains pebbles of quartzite. Its thin faux mur rests on sandstone, which has *Stigmaria* in the upper part. A cross-bedded sandstone is persistent in the faisceau Goufre. The conditions farther west in Hainaut are not materially different from those already described.

The Flénu deposits are confined practically to the district of Couchant de Mons, in much of which the coal is buried deeply, but mining operations are extensive. The coal is much richer in volatile than that of the Charleroi but peculiarities of seams and of the interval rocks are much the same. The lowest seam[63] is the Petit-Buisson, which has a well-marked marine roof, whence Cornet ob-

[63] J. Cornet, "Seconde note sur les lits a fossiles marins," etc., *Ann. Soc. Geol. Belg.*, t. XXXIV., 1907, Bull.., p. 93.

tained *Orthoceras, Lingula, Pernopecten* and *Carbonicola*. Renier[64] states that this coal seam was covered by ocean water soon after deposition, so that at some localities it has been replaced with dolomite. This dolomite encloses the vegetable pulp of the swamp, little changed.

The mass of deposits decreases toward the east. Andenne from 340 to 170 meters; Chatelet, from 400 to 288; Charleroi is 1,270 in Couchant de Mons but only 970 in the Liége district. Four coal seams at most are in the Andenne; the same number in the Chatelet, but they are unimportant except in the Liége district; Charleroi is rich throughout, having 19 workable seams in Couchant de Mons with 10.70 m. of coal, 20 in Charleroi, with 16.85 m., 23 in Liége with 17.45 m. of coal. Flénu in Couchant de Mons has 45 seams with 27.20 m.; besides these, each more than 30 centimeters thick, there are many veinettes, which rarely become thick enough for local operation.

Intervals between coal seams vary almost capriciously. Smeysters[65] notes many instances in the eastern part of Hainaut basin; one may mention here only that between the Mere-de-Veines and the Crevecœur. This interval is usually 10 or 12 meters, but at one locality, it is reduced to 60 cm., yet within a short distance the normal interval was observed. The coal seams are equally variable and some of them, as mentioned by Stainier, resemble a string of huge beads. Several seams are persistent enough to be utilized as horizons, but great variability characterizes all.

Many years ago, Cornet[66] grouped the Belgian coals into (1) houille maigre à longue flamme ou houille flénu; (2) houille maigre à longue flamme ou demi-grasse; (3) houille grasse maréchale ou houille grasse; (4) houille sèche à courte flamme ou houille maigre. (1) is brilliant, with conchoidal fracture, ignites readily, yields much illuminating gas, but the coke is not well fused; (2) has shaly fracture, often has fusain, yields excellent but not strong coke; (3) gives a coke good for all purposes; while (4) burns slowly and the coke is

[64] A. Renier, "Les relations géologiques du Bassin houiller du Nord de la France avec les gisements belges," *Bull. Asoc. Ing.*, Fasc. 1, 1919, p. 18.

[65] J. Smeysters, *Ann. des Mines*, t. V., 1900, pp. 103–106.

[66] F-L. Cornet, "La Belgique Minerale," *Catalogue of Paris Exposition*, 1878, Separate, pp. 18–25.

not fused. He remarks that the volatile decreases downward in the measures but he notes also a variation along the direction of strike and still more notable decrease from the disturbed southern area northward into the slightly disturbed area along the northern border.

Renier[67] offered a somewhat different grouping; Flénus, with more than 25 per cent. of volatile; Gras, with 25 to 16; Demi-gras, with 10 to 11 and Maigre, with less than 11. Gallet, resembling bituminous shale, is closely allied to cannel. The different benches of a seam are often unlike in volatile content and there are local variations which are puzzling. At the same time it seems possible to find a law of variation in order of superposition; equally so in a single seam along general direction of the trough, or even in a direction normal to the line of the trough. The downward decrease is thus, Flénu, maximum, 35 per cent.; Charleroi, 24; Chatelet, 18; Andenne, 15. But in the Flénu, the volatile varies from 25 to 35; in the Charleroi, from 17 to 20 within Couchant de Mons, 17 to 18 in Centre, 10 to 18 in Charleroi, 13 in Basse-Sambre, 0.5 to 21 in Liége district; the Chatelet from 6 to 10 and the Andenne from 7 to 15.5. He thinks that Hilt's law is practically applicable to the Belgian area. But the volatile increases from north to south, that is, from the less disturbed to the intensely distorted area. Finally, the volatile decreases from the outcrop toward the deeper part of the basin.

Dannenberg,[68] utilizing tables of analyses compiled by Stainier, makes clear that, in the Liége district, the volatile of the respective faisceaux of the Charleroi decreases downward from 23.7 in the upper St. Gilles to 6 per cent. in a seam near base of the Seraing. But there are exceptional seams; one in the upper Liége faisceau has abnormally low volatile, being anthracite, while one in the upper portion of Seraing has 24 to 25 per cent. and is the richest gas coal in the district. More important are the variations across the basin from north to south. In the northern portion, the "Plateurs," where disturbance is comparatively slight, the percentage is low, but it increases greatly in the southern portion, where the disturbance

[67] A. Renier, op. cit., 1914, pp. 23–30.
[68] A. Dannenberg, op. cit., p. 285.

was extreme. In four important seams of the faisceau Seraing, the percentages at the north are 13, 7.3, 6.2, and 6, but these increase southwardly to 20.8, 18, 15.5, 16.6.

France.—Passing into the Department du Nord in France, one reaches the Valenciennes basin, which is continuous with the Hainaut basin at the east and with that of Pas-de-Calais at the west. According to Barrois, the Coal Measures come to the surface in a comparatively small area near the Belgian border but elsewhere they are largely covered by later formations, so that mining operations were begun at much later date than in Belgium. During Trias, Jura and Lower Cretaceous time, the Coal Measures were exposed, and erosion removed them from a great area. The limits of the coal deposits have been determined approximately by borings, but the region has been disturbed so seriously by folds and overthrust faults, especially along the southern border, that the succession can not be determined beyond doubt. The basin is from five and a half to sixteen kilometers wide. The coal seams are numerous, fairly uniform, but are thin, rarely exceeding one meter and averaging about 70 centimeters; under favorable conditions, some only 35 centimeters thick, have been mined. The actual number of workable seams can hardly be determined; Olry attempted to ascertain it. Going from north to south, he found in the several faisceaux, beginning at the bottom,

A, in the northern portion,

faisceaux 1, 2, 3, 35 seams; 4, 31 seams; 5, 36 seams;

B, in southern portion,

6, 25 seams; 7, 16 seams; 8, du Marly, 3 seams, in all 146 seams. But paleontological work by Barrois and Paul Bertrand[69] has proved that this number is much too great. The seams appears to be superimposed as Olry supposed them to be, and the change in chemical composition is singularly regular in the order; but certain seams have been recognized in both portions of the region, though differing in facies and in composition. Barrois states that the seams of faisceaux 1 and 8 must be ignored, that faisceaux 5 is superimposed only

[69] C. Barrois, "Exposé de l'etat de connaissance sur la structure géologique du bassin houiller dans le Department du Nord," Lille, 1909, pp. 1–22.

in part upon 4 and so has only 15 seams. The number of workable seams does not exceed 77 and even that estimate may be excessive. The zone of Flines, equivalent to Andenne of Belgium, gives evidence of at elast five invasions by the sea.

The Concession of Dourges was studied many years ago by Breton.[70] He recognized a general decrease in volatile downward in the section, but the change is not in accordance with an exact law, for it is true only of seams far apart, not of those near together. Similar variation is observed in a seam, when followed for a considerable distance. The roof in each case has its own plants along with others not peculiar to it. The exposed section in southern Dourges is about 750 meters thick with 80 coal seams, measuring from one centimeter to a meter and a half. The area is greatly disturbed by folds and faults.

There are 36 beds of sandstone, the thickest being 22 meters. They vary greatly but not abruptly and consist of quartz grains with clay and some mica. Occasionally, they contain pockets of bright coal, and trunks of trees are not rare. Sandstone, at times, replaces a coal bed, though the mur and toït persist in such cases. Shale in roof of a coal seam is darkest near the coal but the best impressions of plants are at about a half meter above. He notes one marine deposit, about 7 meters thick, containing many specimens of *Productus* and *Orthoceras*.

Breton groups the coals into grasses, which ignite readily, are rich in gas, fuse well, give off dense smoke and leave a white ash, and sèches, less easily ignited, burn slowly, give less smoke, do not agglutinate and leave a reddish ash. These often have much mineral charcoal, which bears close resemblance to wood charcoal. Coal seams usually have shale at top or bottom or as partings, which, in the fat coals, is combustible and is used as fuel for the boilers or is given to the poor. He emphasizes the fact that, very often, there is a veinette near a thick seam, with which it is apt to unite.

He groups the deposits into faisceaux. The highest is that of the charbons tres-gras, shown in the eastern part of the Concession. This, about 300 meters thick, has 7 workable seams with 6.15 meters

[70] L. Breton, "Étude géologique du sud de la concession de Dourges," *Soc. des Sci. Lille*, 1872, pp. 355–422.

of coal; 10 which may be utilized when the thicker ones have been exhausted, and 8 which are too thin ever to be mined. The highest seam is the Ste.-Barbe, with maximum of a meter and a half, which is double—a characteristic of the thicker seams. Veine 9, long mined at one colliery, is of uncertain value, for within a few meters it may change in thickness from 3 or 4 meters to a petty veinette. It is always in a single bench and has a faux-toit. The coal is very clean and much prized for manufacture of illuminating gas, though it has little lump. The thickest seam is the Veine a trois sillons, with 0.60, 0.40, 0.40 of coal and 0.30 of bituminous shale in two partings; it yields 60 per cent. of lump coal.

The faisceau de charbons gras, 190 meters thick, has 5 workable seams with 3.50 meters of coal. The seams are irregular and some of them are merely local; one, a meter thick at the west and yielding excellent lump coal, becomes poor toward the east and at length is replaced with sandstone. In its roof are vertical *Calamites*, of which the roots are in the coal. The demi-gras faisceau has five thin but workable seams, one of which has *Stigmaria* in the roof.

Coals from the highest faisceau have 28 to 32 per cent. of volatile, those of the middle have 25 to 28, and those of the lowest have 22 to 25. Breton asserts seams cannot be identified or their position determined by means of composition.

Rock Fragments in Coal.—The presence of rock fragments in coal seams has been observed by Stainier and Schmitz in Belgium and by Barrios in France.

Stainier[71] found rolled pebbles in the 500-meter level of a seam near Charleroi, where they are not uncommon; but none has been found in the 250-meter level. They are rounded and have a coaly covering. The dimensions of two of them are 0.07 by 0.045 by 0.10 and 0.14 by 0.08 by 0.16 meter. These are quartzitic sandstone. A similar pebble from a seam in the Huy district is 0.15 by 0.10 by 0.04, rudely triangular and the edges are rounded. Schmitz obtained from the Veine Leopold near Charleroi sandstone pebbles, perfectly rounded and covered with a crust of coal. Stainier saw large, rounded pebbles in the Grande Veine at Gosselius. They are pres-

[71] X. Stainier, "On the Pebbles found in Belgian Coal Seams," *Trans. Manch. Geol. Soc.*, Vol. XXXIV., 1896, Sep., pp. 1–19.

ent in the Grande Veine of Centre, that of Charleroi, Dix-Paumes, Gros Pierre, Caillette and other seams. Some have been discovered in partings, in the roof and in the mur. The largest weighs 25 kilogrammes and most of them are sandstone. Stainier thinks that these pebbles must have been entangled in roots of trees, floated into the sea.

Schmitz[72] asserts that rolled pebbles are not so rare as some writers have supposed; they are not exceptional but are of common occurrence throughout the coal formation. He thinks that they confirm sympathy for the French doctrine, which assumes that the plant materials were changed into coal before burial in deltas. He suggests that, on the shores of coal lagoons, movements of water more or less rapid had brought fragments of rock with the vegetable alluvium; a long voyage in the *bouillie vegetale* would bring about the coating of coal.

Barrois's[73] exhaustive study was based upon a collection of more than 300 pebbles made in the Veine-du-Nord at mines of the Compagnie d'Aniche. The seam is regular and, though thin, 0.45 to 0.60 meter, it has been mined profitably for a long time. The coal is of excellent quality, demi-gras, with 13 per cent. of volatile and comparatively little ash. The mur has abundance of rootlets and at half a meter below the coal there are many large rhizomes of *Stigmaria* with appendages. The roof is fine shale, without animal fossils, has no erect stems but has impressions of *Lepidodendron* and Calamites. The faux-toit is shale and coal, never more than a half meter thick.

The pebbles vary greatly in shape and are distributed irregularly in the coal from mur to toit. Their position indicates that they were not brought in by currents and some have salient angles, which would have been destroyed by even gentle rubbing. The crust is coal, laminated and brilliant, often with pyrite, derived from the coal. It is adherent, is removed only with difficulty and contains more volatile than is found in the surrounding coal.

[72] G. Schmitz, "A propos des cailloux roulés du houiller," *Ann. Soc. Geol. Belg.*, t. XXI., 1894, Bull., pp. lxxi–lxxv.

[73] C. Barrois, "Galets trouvés dans le charbon d'Aniche (Nord)," *Ann. Soc. Geol. du Nord*, t. 36, 1907, pp. 248–330.

The pebbles differ in character. Some are of feldspathic sandstone, the feldspar being completely decomposed. These, at times, contain fragments of Coal Measures plants. Others are quartzites of types belonging to the Coal Measures; but there are some which appear to be of Cambro-Silurian origin, though without fossils and some are of gneiss. Eighty-six per cent. are from the Coal Measures, 2 from Cambro-Silurian and 12 are from the Archean. The Carboniferous specimens are from the Flines (Andenne) and Chokier assises (Namurien of Stainier). The forms vary; subangular, 63 per cent., and rolled, 37. The weights are 1 gramme to 1 kilogramme, 73 per cent.; 1 to 10 kilogrammes, 24 per cent.; and still heavier, 3 per cent. The largest are of sandstone.

There must have been land where coal rocks and those of earlier age were exposed. The area of outcropping coal rocks must have been extensive and near at hand, as is evident from shape of the specimens. These were from the north side of the trough, where the rocks had become hard before tectonic disturbance occurred. All efforts to explain their presence as due to torrential action must be abandoned. The pebbles had been exposed for a long time; some were wasted by rubbing, others seem to have been worn by moving strata or by wind action; but all evidence shows that they endured long alteration in free air.

Erect Stems—Stainier[74] has described erect trunks observed by him at two localities. At the Falisole colliery, the Veine Lambiotte rests on a sandstone, containing a veinette, which occasionally unites with the main seam. At usually 4 but occasionally 12 meters above the coal is a veinette, which at one locality unites with it. In this interval numerous trunks were seen, but they are without roots and all features indicate that they are merely "snags." At the other locality, the trunks are cut off by faulting, but the evidence presented by Stainier does not suggest that the stems are *in loco natali*. The seam at this place shows signs of erosion during deposition of the overlying sandstone. Smeysters[75] has described the mode of occur-

[74] X. Stainier, "Un gisement de troncs d' arbres débout au Charbonnage de Falisole," *Bull. Soc. Belg. de Geol.*, t. XVII., 1902, Mem., pp. 69–76. The same, 1903, pp. 539–544.

[75] J. Smeysters, "Note sur les troncs d'arbres fossiles," *Ann. Mines de Belgique*, t. X., 1905, pp. 1–12.

rence of several vertical stems in a mine near Charleroi; but these seem to be transported fragments; there is no reason for supposing that they are *sur place*.

Schmitz[76] in 1895 found 33 stumps of erect trees in the roof of the Grande Veine at Grand Bac in the Liége district, where the coal seam is vertical. The glossy, brilliant basal surface of the roof is exposed in the wall throughout and observers could determine the circular markings, indicating bases of the trunks. In almost every case, the cylinders of these petrified trees retained the bark, coalified, sometimes a centimeter thick, under which were leaf scars showing that they are *Sigillaria*. As the stems are vertical to the stratification, detailed study of their surface was impossible. The exposure is on the north wall of the gallery, 2 by 93 meters, giving to each stem a space of 5.60 square meters, a condition favoring belief that they are *in loco natali*. But the stems are distinctly cut off sharply at approach to the coal. Most of them show the swelling which belongs near the roots, but no trace of roots appears. It is clear that the rooting of these trees could not be in the toit, for that is merely a few centimeters of carbonaceous shale. This thin toit contains many impressions of plants and stalks of lycopods and equisetaceæ, all lying flat. Four of these were seen passing across the base of a trunk, which proves that the stems are not *in loco natali*.

But the whole condition indicates rather that the overlying rock, penetrated by the trunks, has slipped on the coal during the disturbance. This polished the surface at the plane of contact and cut off the stems as sharply as though they had been sawed. Schmitz, in a later article, recognized this condition and regarded the forest as *in loco natali*. Long ago, Breton,[77] in his description of the Concession of Dourges, stated that, in some mines, *Calamites* were found normal to the bed, in the place where they grew. The roots often rest on the coal and the stems traverse the roof. In the pit, Ste.-Hermite, one can see in a gallery, 60 meters long, a number of *Calamites*, resting by their thin part on the coal, the stems penetrating the over-

[76] G. Schmitz, "Un banc à troncs débout," etc., *Bull. Acad. Roy. de Belg.*, III., t. XXXI., 1896, pp. 260–266. "Formation sur place de houille," *Rev. des Quest, Scient.*, April, 1906, p. 31.

[77] L. Breton, op, cit., pp. 383, 389.

lying shale, 3 meters thick. Sandstone overlies the shale and it fills the *Calamites* to their roots, which are in the coal. *Sigillariæ* are sometimes vertical to the stratification. *Stigmaria* characterizes the mur and sometimes is found in the roof.

Boulay[78] states that in the roof of mine Veine Christiane within the Concession of Bully-Grenay, in Pas-de-Calais, he saw great erect trunks of *Sigillaria*, 30 to 60 centimeters in diameter. The species was not determinable, but the roots are unquestionably *Stigmaria abbreviata*. This seam is higher in the section than the Ste.-Barbe of Dourges. Bertrand[79] examined two erect stems in a mine within the Lens Concession of Pas-de-Calais. One, in roof of the Veine Désiré and not absolutely vertical, has its base resting on a coaly film; underneath the veinule is abundance of *Stigmaria* rootlets and a great *Stigmaria* rhizome was seen; but this could not be traced as a slip had occurred at the horizon of the veinule, so that no proof could be obtained that this *Lepidodendron* stump is in its original place. The other stump, a *Sigillaria*, was in roof of a seam, 14 meters above Désiré; the broadened base rests directly on the seam and its roots cannot be traced; if it be *in situ*, the roots would be unrecognizable, as they wiuld have been changed into coal. The stump directly above Désiré is cut off at base as though sawed. This is a common condition, observed in other coal areas.

Barrois[80] discussed the matter generally in connection with description of vertical stems at many horizons in the Lens and Liévin Concessions within Pas-de-Calais. The existence of such trees had been known for a long time and they had been regarded usually as being in the place of growth; but latterly some geologists have maintained that they had been transported, A recent discovery of erect trees in the roof of the Veine Leonard of Liévin seems to confirm the later explanation. He presents a diagram, drawn carefully to a scale, which shows the relations. The trees are parallel, are envel-

[77] L'Abbe Boulay, "Recherches de palaeontologie végétale," etc., *Soc. Scient. Bruxelles*, 4me année, 1880, p. 32.

[79] P. Bertrand, "Note sur des arbres, débout à la fosse No. 3 des mines de Noeux," *Ann. Soc. Geol. Nord*, t. 37, 1908, pp. 50,51.

[80] C. Barrios, "Note sur la repartition des arbres débout dans le terrain houiller de Lens et de Liévin," *Ann. Soc. Geol. du Nord*, t. 40, 1911, pp. 187–196.

oped in shale, with roots at the lower end, which do not penetrate the coal; at least, if they do, they have been converted into coal and become unrecognizable.

During a number of years, Barrois, P. Bertrand and some other geologists had studied the roofs of coal beds and they succeeded in classifying them into (1) roofs of sandstone, the grains varying in coarseness, containing much vegetable débris, but leaves have disappeared; (2) roofs of shale, carbonaceous, with plants, the leaves in fine condition, showing that they had not been transported far and that the deposition had been made in quiet, shallow water; (3) roofs of bituminous shale, black, ampelitic, and with fish remains; always very thin; the deposit was made slowly and the water was not free from mud; (4) roofs of bituminous shale, brown, contains lamellibranchs of deep- and brackish-water types; these also were formed slowly and the water was not deep or agitated violently; (5) roofs of calcareous shale with marine shells; the water was deeper and liable to greater movements.

If the trees had been floated in, they should occur in roofs of deep water origin, they should not be in roofs, formed in water so shallow that they could not be introduced in vertical position. But they are present in shallow water roofs. At Liévin, they have been obtained from 19 veines or passees (veinules) with typical shallow water roofs and from 7 roofs of intermediate types. Distinctly deep water roofs are not wanting, there being 28 of them, not one of which contains erect trees. Barrois regards the evidence as sustaining the assertion of *in situ* origin for the stems.

The Central Plateau of France.—The coal basins of central France, about 300 in number, are in large part of little more than local importance; but some of them are extremely important because the seams attain great thickness and yield a high-grade fuel. All are of limnic origin and the Coal Measures deposits belong mostly to the Stephanien. The general features are much the same in all, so that it is necessary to refer only to the basins with which all are familiar.

The Coal basin of the *Loire* or of *St. Étienne* was studied by Gruner, whose report was published in 1882 and by Grand'Eury,[81]

[81] L. Gruner, Bassin houiller de la Loire," Paris, 1882, pp. 168–173, 204–237, 483–486; C. Grand 'Eury, "Bassin de la Loire," *C. R. Cong. Int. Geol.*, Paris, 1900, pp. 521–543, *Livret-Guide des Excursions,"* XIb., 1900.

whose results, chiefly from the paleobotanist's standpoint, were presented in many memoirs. Two papers, published by the International Geological Congress, may be accepted as summarizing his conclusions.

According to Gruner, the succession, ascending is:

Brêche de la base; Étage houiller de Rive-de-Gier; Étage sterile de St. Chamond; Étage houiller inférieur de St.-Étienne; Étage moyen de St.-Étienne; Étage supérieur de St.-Étienne; Étage sterile, or Permo-Carboniferous of Grand'Eury.

These outcrop in concentric curves, now broken and distorted by faults. The basin embraces about 80 square miles; the second and third stages occupy not far from nine tenths of the area, if they exist under the higher divisions; the fourth is present in almost one half of the basin; the fifth, in less than one fourth, while the sixth and seventh are in less than one twelfth.

The Brêche is a confused mass of angular fragments, slides from primitive rocks, surrounding the basin, and nature of the fragments differs according to locality, granite prevailing at some, gneiss at others. It is from 20 to 200 meters thick and the top is at 15 to 20 meters below the lowest coal seam.

The Rive-de-Gier, consisting of sandstone with some shale, is 100 to 120 meters thick and has four workable coal seams, as well as several thin streaks. The highest, Grand Masse, is divided by a parting of white sand, known as Nerf blanc and not more than 10 inches thick. Coal from the lower bench is hard, dull, contains much oxygen, is good fuel for grates and is termed "rafford"; that from the upper bench, termed "maréchal," is tender, brilliant, has less oxygen than the other and is excellent for gas and coke. In the western part of the area, coal from both benches has less volatile than at the east and, in the last concessions, it becomes anthracitic at depth of 500 to 600 meters. At the eastern limit of the Rive-de-Gier, the Grand Masse is from 0 to 0.50 meter thick; but it increases toward the west and becomes 15 meters at Grand'Croix. It thins away at the borders of the area. The roof is sandstone; during its deposition, the coal suffered much from erosion, all having been removed at numerous places; the mur is tender, often swells and replaces much of the coal. The seam, les Batardes, 35 meters lower,

is double with a parting, 0 to 8 meters thick. The coal thickens and improves in quality toward the west, becoming 5 meters near Grand-'Croix, where the benches are united. The roof of the upper bench is sandstone and erosion of the coal is frequent; but that of the lower bench is shale and the coal is always regular. Two lower seams have poor coal; one has maximum thickness of 1.40 meter near Grand'Croix, but the other is a lens, disappearing in all directions.

Beyond the Rive-de-Gier, one reaches the sterile stage of St.-Chamond, 500 to 800 meters thick, the lower portion a coarse conglomerate, the upper less coarse and micaceous. The upper or micaceous division is thin at southeastern localities but it increases at expense of the lower portion until, near St.-Chamond, it has replaced it almost wholly. Thin coal seams occur in the area of coarse deposits but they disappear when the micaceous beds predominate.

The Étage de St.-Étienne inférieur, 850 to 950 meters thick, has 10 to 12 coal seams, some of which occasionally divide. They vary abruptly in thickness as well as in quality of the coal. Seams 8 and 12 at times yield excellent coking coal but at others they are so dirty as to be worthless. Coal seams are regular where the rocks are quartzo-feldspathic but become worthless or disappear when the rocks are micaceous. The upper division has one important seam, 0 to 6 meters thick, which suffered much from contemporaneous erosion, having been removed wholly in many places. The coal is good for coke, though it must be washed to remove the high ash. The coal of this stage was formed of *Cordaites, Psaroniocaulon, Aulacopteris* and *Calamites*.

The Middle stage of St.-Étienne, about 350 meters thick, has 8 or 9 coal seams separable into two divisions; the lower has two seams. In the upper, Nos. 1 and 2 have inferior coal containing kidneys of iron ore and trunks of trees, replaced with carbonate of iron. Ordinarily they are not mined, but No. 2 occasionally becomes 3 meters thick and has good coal. Nos. 2 and 3 are united at many places; the latter averages 4 to 5 meters; No. 4 is ordinarily at 20 meters below 3, but the interval varies from 0 to 24 meters. At times, No. 3 is 10 and 12 meters thick, but in such cases it consists of 1, 2, 3 and 4 united. The coal of this stage originated from the same plants as in the Lower St.-Étienne.

The Étage supérieur de St.-Étienne, 250 to 350 meters thick, is in an area of 1,000 to 1,500 meters wide by 11 kilometers long. It has 10 or 12 coal seams with total extreme thickness of 15 to 20 meters at the east but diminishing rapidly toward the west, where micaceous shales prevail. The lowest seams are of moderate thickness and yield inferior coal. The seams in the middle are 2.50 to 7 meters and are good. The highest seam, 3 to 10 meters, yields friable coal. In all cases the coal is rich in volatile and appears to be composed of *Psaroniocaulon, Stipitopteris* and *Calamites.*

The upper sterile stage or Permo-Carboniferous, apparently not more than 475 meters thick, consists of shaly green and red sandstone. The passage from St.-Étienne is gradual and, as far as can be gathered from Gruner's statements, the succession is conformable.

Gruner notes that the forests of this basin are confined to the Middle St.-Étienne. Long ago, the upper one was described by Alex. Brongniart.[82] Though are rocks are horizontal, they have suffered from a slight movement, which has broken the continuity of many stems, so that the root portion has been shifted. Eighteen vertical stems are shown on the plate, which represents about 75 feet of the wall, and roots are distinct on many of them. Brongniart was confident that this is part of a forest of bamboo-like plants. The interior of the stems is filled with sandstone like that in which they occur; but this is coated by coaly or ferruginous material.

Gruner says that another forest is at 100 meters lower in the section. He saw in the Treuil mine 12 trunks in a space 12 meters square. These rest directly on the coal, which is not penetrated by the roots, though in some cases they spread out upon it. These are *Sigillaria.* Similar conditions were observed elsewhere. The relations in the mur are different from those observed in the roof, for at St.-Étienne he saw rootlets descending from the coal into the underclay. This condition is especially clear in les Batardes of the Rive-de-Gier, where *Stigmaria* abound in the mur. His discussions on pp. 168–173 and 483–496 should be consulted by all who are interested in the matter.

[82] Alex. Brongniart, "The Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines,* 1821; translated in de la Beche's "Selection of Geological Memoirs," etc., London, 1836, pp. 208–216.

Grand'Eury presented to the Geological Congress a paper in which he discussed elaborately the occurrence of various types of plants. He regards the deposits as Stephanien. The paper in the Guide gives more of detail respecting localization.

The Upper Sterile stage passes upward into coarse conglomerate, which Stur thought analogous to the Rothliegende of Rossitz; but there is no unconformity. The Rothliegende flora is not abundant. *Cordaites* and *Pecopteris* are present and *Tæniopteris abnormis* has been found but no trace of *Callipteris* has been observed. *Walchia* pinniformis was seen in the St.-Chamond, but it does not continue into the St.-Étienne stages. The Avaize (Middle St.-Étienne) contains precursors of the Permian.

The Productive Coal Measures show erect trees with their roots, associated with well-preserved plant impressions, all indicating autochthonous vegetation. Rooted trunks and stumps are uncovered daily near St.-Étienne. His belief is that the trees, in every case, grew in water with their roots penetrating the ground below. In many cases, the stems have been removed during mining work but usually the vegetable soil was not disturbed; it is traversed by roots, some herbaceous, some ligneous, which often pierce impressions of leaves. *Stigmaria* is the most common form. These have their roots spread out in normal position and frequently retain the delicate appendages. They penetrate the underclay and are interlaced in it. There are many other types, which he regards as even more satisfactory. Chief among these is *Calamites,* whose erect stems give off rhizomes, which, in turn, give off rootlets; all of the subterranean organs are well preserved and are in normal position. *Calamodendrons* have their stems bound to the soil by a complete system of roots. *Psaronius* stems are very numerous and are surrounded at base by innumerable roots, pushed down obliquely into the soil. When the plant, subjected to accumulation of alluvium, was obliged, in order to live, to give off free roots in the water, these passed downward and buried themselves in the soil below. Stumps of *Cordaites* are equally numerous with their woody roots, divided and subdivided even to rootlets, which have a comb-like arrangement. *Syringodendrons,* with complete *Stigmaria* roots and rootlets are of frequent occurrence. Fossil fruits are abundant. Roots of

stumps are involved in a maze and he has observed cases where the roots of one stump penetrate stumps at a lower horizon. Some long roots cross several layers of subjacent rock. He is convinced that the fossil forests were developed *sur place.*

Commentry.—The petty basin of Commentry, though embracing barely six square miles, is perhaps more familiar to geologists than is any other of the Plateau basins, St.-Étienne alone excepted. It was studied during many years by Fayol,[88] who described it in an elaborate memoir and utilized the results as basis for his well-known Delta hypothesis. This memoir is so detailed and contains so much of interest that it is difficult to prepare a synopsis of the facts bearing on matters concerned in this study.

The basin is a depression in Archean and apparently contains no rocks older than the higher Carboniferous. It is divided into five strips, extending from north to south: Bourdesoulles, at west, containing coarse rocks; Le Marais-les Ferriéres, sandstones, shales and coal seams; Montassiègè sandstones and blocks of rock; Les Pegauds, sandstone, conglomerates, shale and coal seams; Longeroux, at east side, conglomerates. Montassiègè separates the sub-basins of Les Ferriéres and les Pegauds, which together make up barely one third of the whole area and in each case have only a very small space occupied by coal. The coarser rocks predominate throughout, shale and coal being only 4.5 per cent. of the whole mass.

The important coal deposit of les Pegauds has an outcrop rudely resembling the capital letter C. At the easterly extremity, it begins as a single seam of insignificant thickness, but increases along the curved outcrop, dividing and at last thinning away to disappearance on the east side of Montassiègè, where it is represented by 8 thin seams within a vertical section of 200 meters. Southwardly within the curve, it dips at 0 to 50 degrees and finally comes to an end at a depth of 350 meters. Near Longeroux, at the east, the thickness is only a few centimeters, but at the northerly part of the outcrop, the main portion, known as the Grande Couche, averages between 10 and 12 meters for a distance of 2.5 kilometers. Thence westwardly it decreases to disappearance. The coal for the most part is caking and

[88] H. Fayol, "Études sur le terrain houiller de Commentry," Liv. prem. St.-Étienne, 1887.

with long flame, but it varies greatly. One finds it passing from coal to cannel, boghead, bituminous shale and even to sandstone or conglomerate. Sometimes it is clean from floor to roof, 15 or 20 meters; at others, it is divided by intercalated shale, sandstone or conglomerate, up to several meters thick. This great mass of coal is at 500 to 800 meters above the base of the formation, near which are some irregular deposits of anthracite.

The conditions are similar in les Ferriéres, where the principal deposit, apparently contemporaneous with that of les Pegauds, has a curved outcrop and thins to disappearance at both extremities. The coal has less volatile than that in the other sub-basin.

Fine sandstone prevails in les Pegauds, but coarse material is not wanting. One remarkable mass, marking the course of a violent flood, was formed shortly before the beginning of the Grande Couche. It is coarsest midway, where some blocks are of enormous size, but it shades away on each side into fine sand. Another coarse deposit is intercalated in the Grande Couche, but it is only a few hundred meters long and passes into the coal at each extremity of its outcrop. Fragments of Coal Measures rocks are found in all parts of the section. Those of shale, by their form, suggest to Fayol that they were plastic when enclosed. The pebbles of coal usually resemble in composition the coal nearest to them; those of the basal portion are anthracitic; those of les Ferriéres are maigre but in deposits overlying the Grande Couche the pebbles are usually of coal with long flame, though rare specimens of anthracite occur.

The coal occurs in films and in seams. *Calamites* are rare in the roof of Grande Couche but *Calamodendron* abounds. The flora is the same throughout and continues into the Permian; but there is distinct localization of forms. *Lepidodendron* and *Stigmaria* are present in the southwestern portion but are wanting in the eastern. *Knorria, Lepidophloios, Lepidostrobus* are in the roof at western localities. Fish and insect remains are abundant in some portions. Renault studied many specimens of trunks and branches enclosed in the fine sands. Their coal is derived from decomposition of vegetable material; there is no evidence of enrichment by infiltration, as the enclosing sand contains neither coal nor bitumen. At times a

branch is found, which has been changed in one portion into clean, compact coal, while in the other it has become fusain.

Aside from shaly seams, the coal usually has from 6 to 8 per cent. of ash, yields 60 to 62 per cent. of bright coke and gives off gas burning with brilliant flame. Analyses by Regnault and by Carnot give the ultimate composition:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
I........	82.92	5.30	11.78
II........	83.21	5.57	11.22

Cannel is of common occurrence in the Grande Couche as thin streaks or as lenses, which sometimes extend hundreds of meters; it yields a brilliant gas and has from 33 to 58 per cent. of carbon. Fayol seems to be inclined to believe that difference in character of coal may be related in some way to the ash-content; ordinary coal has 5 to 10, cannel, 7 to 12 and boghead 25 to 50 per cent. of ash.

Trunks, branches, etc., are in rocks of all kinds; are usually prostrate, but some are inclined, others erect. There are few in conglomerates, ten times as many in sandstones, 200 times as many in shales and 1,000 times as many in coal. Erect stems are rare in coal and shale, proportionately they are most numerous in the coarser rocks. At one locality, Fayol found a fern stem inverted. Attached branches are rare but many stems retain their roots. Still, the most of them have neither roots nor branches; but there are stumps retaining roots spread out on the underlying deposit, which they do not penetrate. One such stump, with diameter of one meter, showed 15 *Stigmariæ* radiating from it and enclosing a space of about 400 square feet. These *Stigmariæ* are arranged regularly and are flattened. Stems of trees, numerous in the coal, are compressed, the interior portions having disappeared, the rind only remaining, converted into coal.

The roof is of ordinary carbonaceous or bituminous shale, passing upward gradually into sandstone. Commonly it is rich in plant remains. The floor is usually carbonaceous shale, but occasionally sandstone, and the passage to the coal is gradual. There are many cases of contemporaneous erosion. One in the Tranchée de Forêt

removed the roof and much of the coal along a line of 80 meters on the outcrop. About 40 meters of Permian beds remain; the succession is discordant.

Fayol's conception is that the coals were deposited as transported vegetable matter on the sides of the submerged deltas in the lake or in the bays separating them. A remarkable feature observed in the Tranchée de l'Esperance is regarded by him as due to a slide on the watersoaked surface of the delta. The folding is very distinct in a close synclinal where the rocks are different in color from those of the wrinkled Coal Measures beds on one side, where exposures are complete. As the coal has been mined in vast open works, the conditions are well shown in two adjacent excavations. The locality was visited by Stevenson[84] in 1909, who explained the matter very differently. He regarded the light colored rocks of the synclinal as a deposit filling a channel-way eroded after the coal had been consolidated. The distortion of the strata was caused by eruption of a great mass of dioritine, the lateral thrust folding the rocks, crushing the coal into polished lenses and causing shale beds between sandstones to become wrinkled. This thrust produced a horizontal fault under the severely flexed rocks, which is well-exposed in the Tranchées Longeroux and de l'Esperance. The disturbance becomes insignificant east from the former tranchée as distance from the dioritine increases.

Autun.—Permian in the little basin of Autun contains the boghead, which, according to the studies by Bertrand and Renault,[85] consists chiefly of algæ enclosed in a "fundamental matter." It closely resembles the Kerosene Shale of New South Wales.

The deposit is thin and in limited space; it extends north from Autun for about 7 kilometers and is from 150 to 450 meters wide. It disappears away from a certain depth and is represented on the borders only by small lentils, irregularly scattered. The principal lens is from 23 to 25 centimeters thick, but exploitation is profitable as the yield of oil on distillation is very large. The boghead is

[84] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sciences,* Vol. XIX., 1910, p. 198.

[85] C.-Eg. Bertrand et B. Renault, "Pila bibractensis et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun,* t. 15, 1892, sep., pp. 1–93.

homogeneous, elastic, broken with difficulty, is deep brown and has a resinous luster. The lamination, due to colonies of algæ, is often minute and recognizable only on close examination. The "fundamental matter" contains infiltrations, pyrite, calcite and thelotite, the last being an enriching material, coloring the algæ blood-red. Analyses of specimens from two localities show

	Volatile.	Ash.
Margenne	65.6	34.4
Thelots	73.75	26.25

but these were selected specimens; ordinarily the ash varies from 35 to 48 per cent. The organic matter consists of carbon, 80; hydrogen, 10; oxygen and nitrogen, 10; the ash from the two localities named contains

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Margenne	67.7	10.8	15.7
Thelots	60.5	14.4	17.4

The algæ, *Pila bibractensis,* B. and R., belong to the gelatinous group and are fresh-water forms like the fleurs d'eau. No spores, sporangia, sexual organs or embryos have been discovered. These algæ, at times, compose 75.5 per cent. of the whole mass. The "fundamental matter" contains remains of organisms, *Pila,* fish and grains of pollen; the last being in great abundance, 25,000 to 80,000 in a cubic centimeter, indicating showers of pollen. Besides these, are fragments of wood and leaves; but neither cyprids nor diatoms were observed.

The deposit is a lens, formed as cannel in a pond as is the organic mud, which so often is foundation for a peat deposit. The reasons for regarding the thelotite, pyrite and calcite as infiltrates are not very clear. Certainly the source of the thelotite was not ascertained. If it came from the enclosing bituminous shale, it can hardly be regarded as extraneous. Bertrand and Renault think that the boghead was formed in quiet water with little or no current and they regard the fundamental matter as ulmin which was held in solution. It is quite possible that the lime, present in considerable proportion, would suffice to precipitate the ulmin, but in that case it

is difficult to conceive how the supply could be maintained in quiet water. It must be remembered that the proportion of dissolved ulmin is very small: Smith[86] ascertained that very brown water contains only 4 grains to the gallon, and that if the quantity be 6 grains, the color is intensely dark.

It should be noted here that the conclusions reached by Bertrand and Renault have been controverted emphatically by Jeffrey and by Thiessen,[87] who employed improved methods of preparing the material. Jeffrey examined the Autun and other Bogheads and found no algæ but abundance of spores. Thiessen's results were very similar.

Bretagne.—Several small basins have escaped erosion in the area of the lower Loire Riven within Brittany. A general description of them was published by Barrois about 25 years ago, but his work is not now within the writer's reach. The only available notes are by Rolland,[88] presented many years since. These coals, almost anthracite, are regarded now as belonging to the Culm. The deposits described by Rolland are said to extend from Doué in Maine-et-Loire to Nort in Loire-Inférieure, about 40 leagues. He divides the section into eight systems, each with a conglomerate at base, the intervening rocks being sandstones and blackish shales. The first five systems, in each case, contain only thin streaks of coal, but the sixth, Goismard, has two seams, Petit and Grand Goismard, which at times unite and are mined. The upper, Petit, averaging about 50 centimeters, yields a hard lump coal and has as its roof a sandstone, pierre carrée, almost 70 meters thick. Its faux-toit is fine-grained sand, without cement and about one meter thick; it passes downward into a loose material, termed "tourte" by the miners and consisting mostly of decomposed feldspar. The mur of this seam, roof of the Grand seam, is shaly sandstone, 6 to 8 meters thick at the outcrop; at 100 meters down the dip, it is 3 and at 200 it is only 1 meter. In the deepest portion of the works, the seams have

[86] R. Angus Smith, *Manch. Lit. Phil. Soc.*, III., Vol. IV., 1871, pp. 50, 63.

[87] E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.*, Vol. XLVI., 1910, pp. 273–390; R. Thiessen, "Plant Remains Composing Coal," *Science*, N. S., Vol. XXXIII., 1911, pp. 537–552.

[88] M. Rolland, "Notice sur le terrain anthraxifére des bords de la Loire," etc., *Bull. Soc. Geol. France*, t. XII., p. 463.

united and at a short distance beyond the union they disappear. The lower seam, 60 centimeters thick, yields a friable coal. Its mur is a tender shale, which breaks down into a whitish clay. The seventh system has three non-persistent seams and the eighth has but one; these are all thin.

Some sandstones in the fourth have many impressions of *Calamites* and the conglomerate at base contains many large, flattened fragments of stems. Those of the fifth have great abundance of *Calamites,* as well as of trunks of "palms," which are vertical to the stratification and are replaced with sandstone. Occasionally the shales in this system as well as those associated with coal in the eighth, contain impressions of leaves.

The coal is maigre with not more than 13 per cent. of volatile.

Spain.

Barrois[89] devotes 82 pages of his work on the northwestern part of Spain to the Carboniferous of the Asturias. He recognizes three assises: *Assise de Leña,* consisting of sandstones, conglomerate, shales, marine limestones and thin layers of coals; this he regards as equivalent to the Culm of Lower Carboniferous. *Assise de Sama,* equivalent to the terrain houiller moyen of Nord, France, as determined by Grand'Eury and Zeiller after study of the plants. The rocks are sandstones, some persistent conglomerates, rare limestones and numerous seams of coal. *Assise de Tineo,* equivalent to the terrain houiller supérieur of France, composed of shales, sandstones, some conglomerates with pebbles of Coal Measures rocks, and a large number of coal seams. There are no marine limestones. This is not conformable to the preceding deposits and in some areas it rests on the older formations.

Whether or not any representative of Permian exists in the region is uncertain. An earlier student was inclined to assign certain deposits to it, but Barrois thinks that, most probably, they belong to the Lower Carboniferous. The region has been subjected to violent disturbance, faults and overturned anticlines are numerous, so

[89] C. Barrois, "Recherches sur les terrains anciens des Asturies et de la Galice," *Mem. Soc. Geol. Nord, Lille,* 1882, t. 2, No. 1. Citations are from pages 519–600.

that detailed study is not possible in a considerable part of the area. The Coal Measures have an area of about 540 square kilometers in the Asturias and the principal basin is the Central, or Sama de Longres, containing not less than one third of the whole coal area; other basins are smaller, but in some cases are economically important.

The Assise de Leña receives its name from Pola de Leña, north from the Cantabrian Mountains, where the succession is well shown. It is exposed by an anticline in the Central basin, where its character is distinct. Near the montée de Cardeo in that basin, is a conglomerate belonging to this assise, which has aroused much discussion. It consists of large quartz pebbles, grayish white, which are marked in such manner that each observer has felt compelled to offer some explanation; some have regarded the phenomenon as due to chemical action, others think it due to pressure, to heat, etc. Barrois would explain it as due to wind agency. The sandblast produced by winds has had marked effect on quaternary pebbles in the Rhone Valley. Similar blasts could have polished or striated the pebbles of this conglomerate as they lay exposed on a beach. The coal seams of this assise are without economic value.

The Assise de Sama or lower division of the terrain houiller riche of former observers, is the important group of deposits in the Central basin. Coal seams are shown in one section associated with shales and sandstones containing impressions of *Calamites* and *Stigmaria* with nodules of clay ironstone; the coals rest on soft sandstone or shale filled with *Stigmaria*. Near Padrun is a conglomerate containing pebbles of coal, 4 to 5 centimeters in diameter. On Rio Caudal there appear to be about 30 seams of coal, arranged in groups which are separated by barren intervals. The mur usually is a compact shale crowded with *Stigmaria* and fragments of plants, but the toit has abundant beautiful impressions. A faux- toit, 10 to 15 centimeters thick, consisting of shale and coal, often covers the coal and at times is pulverulent. Barrois determined that the number of coal seams reported by earlier observers is far too great and that those who reported 72 to 80 seams failed to recognize several folds; he intimates that most probably the number is too great by at least one half. Throughout this basin, seams show much

variation in thickness, some, at times, thinning away to disappearance. One seam attains 3 meters; in one case coal only 30 centimeters thick is mined. Coals of the same age are in the small Santo-Firme basin, where the formation, resting on the Devonian, is about 500 meters thick and contains 10 coal seams. It underlies post-Carboniferous rocks. The coals show the usual tendency to vary in thickness, sometimes thinning away only to reappear within a short distance. A marine shale, rich in fossils, is roof of a coal seam in upper part of this assise.

The Assise de Tineo is confined to some small basins in the western and to two in the northern part of the old kingdom. In Tineo basin these rocks rest on the Cambrian. In Arnao and Ferrones they rest on Devonian and, because of faults, appear to be intercalated in rocks of that age. The basins of Ferrones has but one coal seam and the overlying Devonian contains fine fossils.

The province of Oviedo had 210 mines in 1869. Studies by de Aspiroz and by Paillette proved that the composition of the coal is not the same in different basins and that it varies even in the same assise. The most of the coal is bituminous but a maigre, anthracitic coal is obtained in Viñon and Calunga basins; this, of no value, may belong to the Assise de Leña. Volatile in the Central basin, belonging to the Assise de Sama, is 30 to 45 per cent. and the ash is from .04 to 3 per cent. But these are only of selected specimens. Coals from the small northern basins have theoretical interest. These give, according to analyses by Paillette:

	Volatile.	Ash.	Fixed Carbon.
Arnao	39	20	40
	49	7	42
Ferrones	45	12	42
	47	2	49
Santo Firme	38	5	55
	46	8	44

The Santo Firme coal belongs to Assise de Sama, that from Arnao and Ferrones, to Assise de Tineo. The difference in volatile might be attributed to the age of the coals, Santo Firme, the older, having less volatile; but Barrois thinks that another explanation, more satisfactory, may be found in the relation of composition to strati-

graphical disturbance. The Sama seams crop at many places where faulting and folding are marked, but in Arnao and Ferrones the disturbance is far greater; the section has been overthrust and the Carboniferous underlies Devonian. The coals which are richest in volatile are from areas which have suffered most severely from pressure. He notes, as bearing on the matter, that Gosselet had shown for the Nord area in France that the northern part of that region had suffered very little from disturbance while, in the southern portion, disturbance had been violent, there being at times complete inversion of the section. Yet coals are maigre in the northwest portion, whereas in the southwest, locality of greatest disturbance, one finds the fattest coals.

Great Britain.

The boundary between Permian and the Coal Measures is not always distinct in England. The unconformity is often small and it is difficult to determine a plane of separation, as rocks of the Upper Coal Measures closely resemble the type, which at one time was thought to be characteristic of the later period. But in considerable areas, the case is clear, for Permian rests on upturned, eroded Coal Measures. There appears to be good reason for believing that the system of flexures, traceable from England across France and Belgium into Prussia, originated toward end of Coal Measures deposition.

Permian deposits of Great Britain are equivalent to the Zechstein and Rothliegende of the Continent, as Murchison[90] held. They are absent from southern England and Wales and Hull believes that that area was exposed to denudation during the Permian interval. The Zechstein (Magnesian Limestone) has escaped erosion in only petty areas but the Rothliegende, covering extensive spaces in several fields, is thoroughly well marked, consisting chiefly of red and purple marls and sandstones, with occasional conglomerates and sometimes, on top, a breccia, containing fragments of trap and Silurian rocks. In the South Staffordshire coal field, the thickness

[90] R. I. Murchison, "Siluria," p. 347; E. Hull, "Coal-Fields of Great Britain," 4th ed., 1881, p. 524.

is estimated by Jukes[91] at from 1,000 to 3,000 feet, but the lower portion is almost beyond doubt of Coal Measures age. In other fields it is much less. Coal rarely occurs; Jukes notes a local seam, 10 inches thick and resting on fireclay. Numerous casts of *Sigillaria* were obtained from red sandstones lower in the section.

The Carboniferous deposits have been grouped into:

Upper Carboniferous. Upper Coal Measures; Middle Coal Measures or Pennant Series; Lower Coal Measures or Ganister Series; Millstone Grit.

Lower Carboniferous. Yoredale Shales, equal in part to Pendleside; Carboniferous Limestone.

Classification of the Coal Measures is perplexing and field workers have employed designations in the local sense. Kidston has offered a grouping based on an elaborate study of the plants:

Radstockian Series; Staffordian Series; Westphalian Series; Lanarkian Series.

The first two are the Upper, the third is the Middle, while the fourth includes the Lower Coal Measures and the Millstone Grit.[92]

Happily, the matters involved in this study have, except in a few cases, little to do with questions of classification, so that, in preparation of synopses of reports, it is sufficient usually to accept the grouping employed by the authors.

The South Wales Coalfield.—This, in the southern portion of England and Wales, was restudied by A. Strahan, W. Gibson, R. H. Tiddeman and T. C. Cantrill.[93] It extends from Monmouthshire at the east to Pembrokeshire at the west. The Permian is not present but the Carboniferous, Upper and Lower, is well marked. The Coal Measures are readily divisible into Upper, Pennant or Middle, and Lower, which are now regarded as equivalent to those of other fields. The Millstone Grit is persistent and characteristic; it and the Coal Measures thicken greatly toward the east; but their total

[91] J. B. Jukes, "The South Staffordshire Coal-Field," 2d. Ed., 1859, pp. 12, 13.

[92] This classification was presented first in 1888, but the final statement with explanations is given in R. Kidston, *Trans. Roy. Soc. Edinb.*, Vol. I., 1914, pp. 74, 75.

[93] "The South Wales Coal-Field," Parts I.–X., Geol. Surv. Mem., 1899–1912.

thickness is much less than was estimated by the earlier survey. The Lower Carboniferous limestones and shales are without coal.

The Upper Coal Measures, consisting of shales and sandstones with mostly irregular coal seams, has at base a well-defined persistent coal, known as Mynyddislwyn, Llanwit I, Wernffraith and Swansea in different districts. A vertical section of 111 feet in the Blackwood Valley near Newport of Monmouthshire, shows six coals, 6 to 30 inches thick, but they are extremely irregular. The Mynyddislwyn is double and the parting varies in thickness; in one area, it varies from 2 to 24 feet; in another, from 6 inches to 15 feet, while in another the parting of 2 feet becomes 15 feet within a short distance. Crossbedded sandstone is not unusual in the eastern part of the field.

The middle division or Pennant Grit is for the most part a clayey somewhat feldspathic rock at the east, which thickens very rapidly toward the west, where it is broken by shales. No workable coals are known at the east but southwardly and westwardly several seams become workable, though as a rule the coal is of inferior quality. The Tillery Coal, known in portions of the field as the Brither, Rhondda 2, Ynysarwed and Garn Swilt, is at the base. This Grit has occasional bands of conglomerate, containing quartz pebbles and rounded fragments of ironstone, coal and Coal Measures rocks. In Glamorganshire, where shales are in upper part of the Pennant, there are three workable seams, while farther west some coals are important. A crossbedded sandstone is the roof of Rhondda 2; at others that roof is conglomerate with pebbles of ironstone and coal; this is common in western localities.

The Lower or Steam Coal Series consists very largely of shale at the east but sandstone increases toward the west. It contains the coals which have made the field so important. In the upper portion, below the Tillery Coal, there occurs a notable thickness of red shale, which is very characteristic along the eastern side. The rocks generally show much variation, thickening rapidly toward the west, where they become coarser.

The coal seams change much in structure as well as in quality, but some of them are so persistent as to be definite stratigraphical horizons. The best-marked seam is that known as the Rock, Black,

Ras-Las, Nine-feet, Bydylog in different parts of the field; its variations may be taken as typical. At most localities, it is double with a variable parting of clay, but there are definite partings, without inorganic deposit, separating benches, differing in the character of their coal. At some localities, it is troubled by "nips," the shale roof disappearing and the underclay becoming sandstone, while the coal thins away. In some districts there are considerable areas where the coal is so poor that it is not worth mining; yet, in most localities, it is a thick bed and yields excellent coal.

"Washouts" are by no means infrequent. The Ras-las is missing at one place in northern Monmouth. In the Ebbw Valley of the same county, a great washout was encountered, extending 1,200 yards and causing removal of a section, 116 yards thick, with three coals, Three-Quarters, Black and Yard. The Ras-las has been washed out for not less than a mile in the Sirhowy Valley; in the Bargoed-Taff Valley it has been rendered almost worthless at many places by wedge-shaped masses of shale, cutting down to or nearly to the base of the seam, but not below it. These resemble channels of rivulets, filled with mud before deposit of the overlying rocks. Local deposits of coal are not unusual. De la Beche[94] saw, near the village of Bagelly in southern Pembrokeshire, some irregular masses of stone coal. One, semi-oval, is 140 yards long, 40 wide and 10 deep; four others of similar type were observed. Such coals seem to characterize the Millstone Grit, since all are local. Cannel is not abundant; it may be on top or midway in a coal seam, but it is always in contact with the coal. A seam, one foot thick, was seen at one place, but it appears to be local.

Strahan[95] has emphasized the plasticity of shale when between more resistant rocks as shown at some places in the Neath Valley. There as well as in Cynon Valley near an overthrust fault, the Nine-feet coal has a layer of shale pressed in to close wrinkles; the coal has become schistose, weathering into plaquettes, with razor edges, slickensided and very brittle.

The lower shales and sandstones of the Lower Coal Series have

[94] H. T. de la Beche, "On Geology of Southern Pembrokeshire," *Trans. Geol. Soc.*, II., Vol. 2, 1829, p. 19.

[95] A. Strahan, Part IV., p. 16; Part V., p. 65.

yielded many trunks of trees, some of which are now in the Museum at Swansea. Many years ago, de la Beche and Logan[96] saw two erect stems near the head of Swansea Valley in Glamorgan; the shale underlying the sandstone was uncovered and found to contain abundance of vegetable remains, proving it to be a vegetable soil, but the statement does not indicate that roots were found attached to the stems. The trees were *Sigillaria;* vertical stems of this type occur frequently.

Coals in this field decrease in volatile content downwardly; the Upper and Pennant coals are gas, while those of the Lower Series are steam coals. But the variation is more marked in all seams as they are followed westward; gas coals become steam coals and the steam coals become anthracitic until at last in the western portion anthracite prevails. It should be noted here that the total thickness of measures in the anthracitic area is very much less than was estimated by the earlier surveyors. Strahan[97] has given an elaborate discussion of the conditions, which well deserves careful consideration.

The South Staffordshire Coalfield.[98]—This is chiefly in the southern part of Stafford but extends into the adjoining counties of Worcester, Shropshire, Warwick and Salop. The region has undergone great disturbance and correlation is hardly possible in some portions, but the relations are clear in the northern districts. The Lower Carboniferous and the Millstone Grit are not reached but the Permian and the Coal Measures are present. The boundary between these formations had not been determined at the time when Jukes wrote; they appear to pass gradually one into the other. No unconformity has been seen between Coal Measures and the deposits taken to be Permian. The latter according to Jukes are from 1,000 to 3,000 feet thick and are extremely variable. Observations by geologists in recent years make more than probable that the lower part of this Permian belongs to the Radstockian Series of Kidston.

The succession below Permian, according to Jukes, is: (1) The

[96] H. T. de la Beche, "Geological Observer," Amer. ed., 1851, p. 482.

[97] A. Strahan and W. Pollard, "The Coals of South Wales," etc., Mem. Geol. Survey, 1908, pp. 65 et seq.

[98] J. B. Jukes, "The South Staffordshire Coal-Field," Mem. Geol. Survey, 2d ed., 1859.

Halesowen Sandstone Group; (2) The Red Coal Measures Clays; (3) The Coal Measures. The first and second are each about 300 feet thick; the Coal Measures have a minimum thickness at the south of about 400 feet and increase northwardly to possibly 1,300.

The Halesowen Sandstones and the Red Clays were thought for a long time to be Permian, but careful study by Ramsay, Hull and Jukes fixed their place finally in the Coal Measures. The Halesowen sandstones are olive-green, brownish to yellow sandstones with two thin coals. They rest on a mass of red, green and mottled clays containing a thin coal, occasionally 9 inches thick. The predominating color is red.

Six persistently important seams of coal are present in the Coal Measures along with a much larger number of thin or dirty seams, which are without value. Among the latter is the Herring Coal in upper part of the section; it is a local deposit, almost worthless as coal, but is of interest because it contains great numbers of fish spines, whence the name given by miners. The remarkable feature in this field is the tendency of coal seams to divide, shown most strikingly by the Thick Coal. This seam, with a roof of black shale, consists of 8 to 14 benches, resting directly on each other or separated by thin partings of clay or shale. Each bench has its own name and retains its character throughout the Thick Coal district. At 2 miles north from Dudley there are eleven benches, with about 36 feet of coal, and partings, in all, amounting to 3 feet; at 1 mile east from Dudley it has 28 feet of coal in 12 benches and less than 2 feet of partings. The Top Slipper and the White, in upper part of the seam, are the best house fuels, but next best are the Sawyer and Slipper in the lowest fourth. The best coking coals are from the Tow, below the top fourth, and the Benches at the bottom, both of which contain much mineral charcoal. These are the conditions near Dudley but changes appear quickly in exery direction. Northward, the Roof and Top Slipper pass off as a separate seam, the Flying Reed, which, at Cosely, is 84 feet above the Thick, and at Billston still farther north, the interval is 208 feet. The Flying Reed thins away not far from Billston. The Thick and the Brooch Coals are almost parallel in this area, the Flying Reed diagonaling between them. The other benches of the Thick show a similar

tendency to separate and eventually that seam appears to be represented by 9 seams in a vertical section of about 400 feet. The same features were observed in other seams, though to less extent. The Heathen Coal, at about 20 feet below the Thick in the Dudley area, is at times 43 feet above the Lower Heathen, though these are united in some districts. The New Mine Coal divides near Bentley into two seams, separated by 33 feet of sandstone and shale; and the Bottom Coal parting, ordinarily 1 foot, becomes 50 feet.

The coal seams show as elsewhere variations in thickness and in quality, but these are most marked where the area is near the original limit of the seam. The coal is bituminous throughout. There is little cannel.

Much red and mottled clay and clunch is present above and below the Thick Coal; similar rock occurs near Brierley Hill in the lowest portion of the Coal Measures. Crossbedded sandstone is not wanting and there are many beds of ironstone.

"Rock faults" and "swells" occur only too frequently. At the Old Baremoor colliery, the measures are regular, but at the New Baremoor, the upper portion of the Thick Coal, 9 feet thick, rests on 42 feet of sandy shale, below which are 44 feet of "rock binds" to the Heathen Coal, which at times is replaced by the rock. The lower part of the Thick Coal fringes out on both sides into the rock mass. This is 282 yards wide and it has been followed northward for 400 yards without reaching the end. The bottom of this rock descends toward the north, cutting the lower bands of the coal and the underlying rocks to the Upper Heathen Coal. Thin wedges of sandstone extend into the coal. "Swells" are risings of the floor, often one or two hundred yards long. Jukes thinks that they may have been merely heaps of sand or mud. An important "swell" in the Baremoor colliery showed that partings in the coal thickened appreciably as they approached the swell, with which they united.

There is complete conformity throughout the Coal Measures, Ironstone beds in many cases contain numerous marine fossils.

The North Staffordshire Coalfield, surveyed by Gibson,[98] has the sequence complete. The Upper Coal Measures or the Red and Grey

[99] W. Gibson, "The Geology of Coal and Coal-Mining," London, 1908, pp. 175–182.

Series of Gibson, consists of the Keele, Newcastle and Etruria Marl groups. The Keele is equivalent to the lower part of the Permian of South Staffordshire while the other groups answer to the Halesowen sandstones and Red Coal Measures Clays of that field. The Keele is the Radstockian of Kidston and the other groups form his Staffordian. The total thickness is 2,200 feet. The Grey Series is grouped into Black Band, Middle and Lower Coal Measures with thickness of about 5,600 feet. The Millstone Grit and the Lower Carboniferous, which are reached at the northern side of the field, are without economic interest.

The Keele consists of red sandstones and marls, which are easily distinguished from the Etruria Clays and from those which occur at various horizons in the Middle and Lower Coal Measures. The Newcastle group, largely sandstone, contains four thin coals, but Keele and Etruria are barren.

The Black Band, only 400 feet thick, has three or more coals associated with the valuable deposits of black band, but the important seams are in the Middle Coal Measures, there being 13 of workable thickness and yielding good coal. Most of them average almost 6 feet, seldom reaching 8 feet. Several workable seams are in the Lower Measures. In greatest part, the coals are steam or house fuels, but as they approach the anticline or western boundary of the field, they often change into coking and gas coal.

Marine fossils have been obtained from 9 horizons, the bands being distributed in the column from base of the Coal Measures up to within 700 feet of Black Band. The Keele group has 3 horizons, from which *Spirorbis* has been obtained; these horizons have been recognized in deposits overlying the Halesowen Sandstones in South Staffordshire.

The Lancashire Coalfield.—This is one of the most important in England. Bolton[100] gave a summary description of it in 1897, utilizing results of studies by himself and earlier observers. The Permian deposits in the Pendle range rest on upturned and denuded edges of Coal Measures and pass beyond them to the Millstone Grit.

The Upper Coal Measures, best shown in the Manchester area,

[100] H. Bolton, "The Lancashire Coal Field," *Trans. N. Y. Acad. Sci.*, Vol. XVI., 1897, pp. 227–239.

not far from 2,000 feet thick, consists of reddish shales and sandstones with some thin limestones. At Bradford colliery, near Ardwick, 7 coal seams, 10 inches to 3 feet 6 inches, were found in a section of about 700 feet. These have been exhausted. The Middle Coal Measures, not far from 3,000 feet thick, contains about 10 workable seams, which are practically persistent, though some of them vary greatly. The coal is apt to be inferior when the thickness exceeds 4 feet, as it is injured by increasing number of thin dirt-bands. The Wigan cannel has abundance of fish remains and *Stigmaria*. The sedimentary deposits are extremely irregular, hundreds of feet of shale at one place being represented by a few feet of sandstone at another. A notable mass of red sandstone, with plant remains and 146 feet thick, rests on the Blenfire Coal at Glodwick colliery in the extreme eastern part of the field. The Lower Coal Measures, about 1,200 feet thick, has numerous seams but, for the most part, they are thin. The Bassey or Salts Mine Coal has a maximum of 23 feet, but its coal is inferior and little used. The Ganister, where thickest, has two benches, Upper Foot and Ganister; when united, the bed has thickness of 8 feet, but in a large area these are separated, the interval reaching 30 feet, and the benches become 2 feet 6 inches and 8 inches. The Millstone Grit, about 5,000 feet thick, has a thin coal seam in the upper division or Rough Rock, and another lower down. Casts of *Lepidodendron, Sigillaria* and *Calamites* are numerous in several sandstones and the shales often yield marine fossils.

Hull's[101] studies have supplied most of the information available for this field. In one of his memoirs, he has described in detail the Wigan area, central in the field. The Permian, chiefly red sandstone, is not found anywhere in contact with the Coal Measures, but the unconformity is beyond doubt, as Upper Coal Measures are not present at some localities where undoubted Permian occurs. It contains no coal.

The Upper Coal Measures, about 1,500 feet thick, red and gray sandstones and marls with bands of limestone, has no workable coals. The Middle Coal Measures, about 2,500 feet thick, and con-

[101] E. Hull, "The Geology of the Country Around Wigan," Mem. Geol. Survey, 2d Ed., 1862, pp. 1–39.

taining all of the thick coals, consists of reddish, gray, yellow sandstones and shales with coals and fireclays. The last are rich in *Stigmaria.* The Coal seams vary much in quality as well as in thickness. In the western part of the area, one portion of the section contains only unimportant coals but in the eastern part, near Wigan, it has, beside some thin streaks, the Haigh Yard, an excellent coking coal, as well as the King and the Cannel. The King has a maximum of 7 feet near Haigh, but thence as a center it thins away toward north, west and south. The Cannel has chief importance near Wigan, where it is 3 feet thick; but it is a lens, thinning away in all directions and it is represented by ordinary coal toward the eastern border. This and the King coal are almost in contact in a considerable area, but northwardly they separate until the interval becomes 60 feet. A cannel, 2 feet 3 inches, is in the St. Helen's section at several hundred feet above the place of that at Wigan, but it disappears northwardly and is represented by black shale at Wigan.

The Lower Coal Measures, about 1,800 feet thick, consists of micaceous flagstones, shales with thin coals. The fourth seam is the Ganister resting on a silicious underclay; the third is the Bullion Coal in whose roof are the "bullions," nodules of argillaceous limestone with *Goniatitis.* Marine fossils are found in the black roof shales. The Millstone Grit, coarse grits, flagstones and shales, has only two or three thin coals.

The sandstones of the Coal Measures and Millstone Grit are often reddish. Those of the Grit are in great part crossbedded, while those of the Coal Measures are described as "generally crossbedded, micaceous, ripple-marked and exhibit sun-cracks, perforations and tracks of annelides and perhaps of mollusks." The roof of the fifth coal of the Lower Coal Measures has vertical *Sigillaria.* The Ince 4-feet coal, near top of Middle Coal Measures, has thousands of vertical stems in its roof throughout the Wigan district. *Anthracosia* and *Anthracopteria* are at several horizons in the Middle Coal Measures and marine fossils are abundant in the Lower Measures. The Wigan cannel contains *Megalichthys, Holoptychius, Ctenoptychius* and *Diplopterus.*

No "washout" is noted by Hull or Bolton.

The Yorkshire Coalfield was described elaborately by Green[102] and his associates. It contains the whole column from Permian to the upper part of the Lower Carboniferous. The succession is: Permian, represented by the Magnesian Limestone, the Zechstein; Upper Coal Measures, perhaps 150 feet; Middle Coal Measures, about 3,500 feet; Lower Coal Measures, about 1,600 feet; Millstone Grit, perhaps 2,000 feet; Yoredale Shales; Carboniferous Limestone is not reached.

Permian and Upper Coal Measures deposits remain at very few localities and for the most part the boundary is obscure, for the relations of the lower beds are in dispute. The Magnesian Limestone rests unconformably upon the rocks in question. Near Pontyfract is a great sandstone, averaging not less than 75 feet, resting on about 40 feet of purple shale and yellow sandstone. It seems to be conformable to the underlying beds but is distinctly unconformable to the overlying Magnesian Limestone. This rock was referred by Smith and by Sedgwick to the base of the Permian, their conclusion being due in great measure to the red color, but Green asserts that this cannot be taken as criterion, for red color characterizes many deposits, which belong undeniably to the Coal Measures. Near Conisborough, the Pontefract is wanting and the Magnesian Limestone overlies 34 feet of very red beds. These rest conformably upon the underlying beds and contain Coal Measures types of *Neuropteris, Sphenopteris* and *Stigmaria*. The Red Rock of Rotherham, a great mass of sandstone and shale, occupies a trough eroded in the Middle Coal Measures. Its age is in dispute and Green declines to commit himself to either interpretation. The mass is certainly unconformable to the Coal Measures but a distinct exposure at one locality shows it distinctly unconformable to the undoubted Permian beds above.[103]

Coal seams are the most nearly constant deposits, because formed in swamps; but swamps must end somewhere; at their margins coal becomes impure, is split by increasing number of clay or sand layers until at length it is replaced with sandstone or shale. Evidence is

[102] A. H. Green, R. Russell and others, "The Geology of the Yorkshire Coal-Fields," Mem. Geol. Survey, 1878, pp. xiii and 823.

[103] Green and Russell, pp. 481–486.

ample, showing that there were many contemporaneous swamps, separated by low divides; their coals are at the same horizons but conditions must have differed locally, for the coal is not the same in all. The existence of such separated areas is distinct at many horizons. The Ganister Coal is present in the southern part of the field but is wanting at the north. The Better Bed is very irregular at the south but is important at the north. The Silkstone Coal is very good near Cawthorne, but thence for a long distance it is badly broken; when the regular seam is reached again at this horizon, it is of different character. More striking is the occurrence of petty isolated swamps, occupying depressions on surface of great sand heaps. Many seams are important only within very limited areas and sometimes a whole group of coals disappears.[104]

The composition of the coal in the several benches of a seam is rarely the same and occasionally the difference is notable. One bench may yield semi-anthracite and another bituminous coal; that from one bench may be caking and that from another may be non-caking. Variations of this type are so numerous as to be commonplace.[105] Cannel, the "stone coal" or miners or, if it contain high ash, "johnnies," is not rare. It has no definite position; it may be at the top or bottom or in the middle of a seam; a whole seam may consist of cannel; but in every case it is lenticular.

The coal varies in thickness as well as in quality. A great many seams are worthless because of ash or sulphur; even in any seam one bench may be clean, another dirty; the coal at one mine may be excellent, at another near by, it may be unfit for use. Faux-mur and faux-toit are characteristic, inferior coal at top or bottom or both being reported from many localities. The faux-mur of the Silkstone Coal is crowded with *Stigmaria* at one mine. The roof of the Ganister Coal has marine fossils in the shale as well as in the "bullions."[106] Marine fossils are in the roofs of several coals in the Millstone Grit. These occur rarely in the Middle Coal Measures and the black shales containing them are thin.[107]

[104] Op. cit., pp. 20, 21, 128, 242, 294, 300, 400, 410, 441 and many others.

[105] Op. cit., pp. 270, 271, 281, 382 and others.

[106] These have been studied by M. C. Stopes and D. M. S. Watson, *Phil. Trans. Roy. Soc.*, Ser. B, Vol. 200, 1908, pp. 167–208.

[107] Green and Russell, op. cit., 40, 63, 70, 71, 110, 230, etc.

Coal seams are rarely single, usually are divided into benches by partings of clay or sandstone which may vary greatly in thickness, though ordinarily the variations are within narrow limits. At times they are great enough to render the identification of seams more than perplexing. The Beeston Coal has its two benches in contact at Beeston, but within a short distance they are separated by an interval of 30 feet. Three seams of the Brown Metals Group show notable changes in relative positions; the interval between Number 1 and Number 2 is 6 inches to 56 feet, and that from Number 2 to Number 3 is from 12 to 66 feet. Other illustrations are noted, but these suffice for illustration.[108]

Contemporaneous erosion is by no means unusual and at some localities its work was extensive. In this, one may see evidence of areal changes of level. Near Penistone, a tunnel has disclosed proof that the region was exposed to denudation for a time in the early part of the Middle Coal Measures. A hill of Coal Measure sandstone remained, against which shales and two coal seams abut, which were formed in the valley around the hill. The Handworth Sandstone, southeast from Sheffield, occupies a valley eroded in the underlying shales, but is conformable to the overlying measures. The great red sandstone of Rotherham is unconformable to the underlying measures, occupying a broad valley cut in them. Coal seams are troubled by "rock faults" of one sort or another. The Old Hards Coal is wanting in some collieries, having been replaced with a deposit containing pebbles and water worn bowlders. The Haigh Moor Coal, one of the most important seams, is injured so badly by rock filling the lines of old watercourses, that in one district it is practically worthless. The "faults" are from 8 to 70 feet across and have northwest-southeast direction. At times they are irregular, there being broad bands of sandstone, connected by narrow strips, which suggest a series of ponds.[109]

The Silkstone Coal (Middleton Main) is troubled by "splits," which re-unite. Kendall[110] examined one at Whitwood, where the

[108] Green and Russell, pp. 185–192, 289–298.

[109] Green and Russell, pp. 140, 281, 343–345, 397, 482, 689.

[110] P. F. Kendall, "On the splitting of Coal-Seams by Partings of Dirt," *Trans. Inst. Min. Eng.*, Vol. LIV., 1918, pp. 1–21.

Top Coal rises until it is 29 feet above the Bottom, thence descends until the two benches are again in contact: the same condition is shown in a second drift as well as in a neighboring colliery. This phenomenon is not rare; it has been observed in several seams within the Yorkshire field and geologists have reported its occurrence in other fields. Kendall thinks it is due to the filling of a channel with sand or clay, over which the swamp extended. The originally level top of the in-swept material is now convex while the originally convex bottom is flat. He conceives that during conversion of the peat into coal, the thin borders of the enclosed mass adjusted themselves to the changing thickness of the organic material until the upper surface became convex and the bottom flat. The existence of the gravel deposit has been proved along its west side for about 5 miles; the mass has been crossed by drifts at two places, which show a width of not less than 1,200 feet. Existence of such "splits" is known in the Silkstone Coal at many places, but these have not been connected by continuous workings. Kendall feels justified in asserting that the splits mark courses of ancient streams.

Limestone rarely occurs in the Yorkshire field, the prevailing rocks being sandstones, shales and underclays. The mollusks are mostly *Anthracosia* and *Anthracomya,* which are at many horizons, but undoubted marine forms are present in some thin black shales. The sandstones vary from conglomerate to fine-grained. The coarser rocks are irregularly bedded and in many cases they resemble huge heaps, thinning away in all directions. But there are such deposits, especially in the Millstone Grit, of vast extent and showing little variation in thickness or character. *Lepidodendron* and *Calamites* casts are not rare. Nearly all sandstones, coarse and fine alike, are false-bedded, often with marked current- or cross-bedding, and the finer sandstones frequently are ripple-marked. Shales may be sandy, blocky, passing into sandstones, or they may be argillaceous; sometimes they are black, passing occasionally into cannel. Underclay, known as Spavin or Seat Earth, is usually clay, always unstratified, never splits into layers, breaks into irregular blocks and always contains *Stigmaria,* with rootlets ramifying in every direction. "Many instances have been observed where fossilized trunks

of trees, still standing erect in the position in which they grew, and attached to their roots, rise out of an underclay." At times, the underclay underlies carbonaceous shale. Ganister is a very hard silicious earth, which is seat to numerous coals, especially in the Lower Coal Measures.[111]

Green mentions (p. 123) that an erect stem was seen rooted in a thin seam of coal and passing up into sandstone. Sorby[112] gave a brief note respecting erect stems, which he saw at Wadsley. In preparing the surface for a public building, the workmen exposed a considerable number of such stems. Sorby induced the authorities to construct sheds in order to preserve the finer specimens. The trees appeared to have grown in what is now a clay-like shale, then died and become decomposed to the top of the surrounding mud. They were hollow stumps and were filled with sand like that of the overlying sandstone. The stems are *Sigillaria* and the roots are *Stigmaria*. The largest and best specimen has diameter of 5 feet 2 inches and the top is not ragged. The roots, which bifurcate, are shown well to a distance of 6 feet from the stump. A prostrate stem lay alongside. Five stumps were exposed in a space of 40 or 50 yards.

In the *Northern field,* within Durham and Northumberland, coal seams make their appearance in the Lower Carboniferous and attain some economic importance. These become valuable in portions of Scotland, where they are the source of fuel supply for leading industries. It is unnecessary to dwell on the several fields, as, for the most part, the general conditions differ in the Coal Measures very little from those observed in England. It will suffice to make reference to but one field in Scotland.

The coalfield of the *Lothians* is in Edinburghshire and Linlithgowshire. It was studied long ago by Howell, Geikie and Young but more recently was examined in detail by Cadell.[113] The suc-

[111] Green and Russell, pp. 14, 17, 37, 58, 60, 97, 114, 140, 300, 323, 402, 437, 470, 496, 649, 666.

[112] H. C. Sorby, "On the Remains of a Fossil Forest in the Coal Measures at Wadsley, near Sheffield," *Quart. Jour. Geol. Soc.*, Vol. 31, 1875, p. 458.

[113] H. M. Cadell, "The Geology of the Oil Shalefield of the Lothians," *Trans. Edin. Geol. Soc.*, Vol. VIII., 1901, pp. 116 et seq.; Mem. Geol. Survey, 1906, 1910; "The Story of the Forth," Glasgow, 1913.

cession as determined by him is: Coal Measure, 1,000 feet, red sandstones above, coal seams in lower portion; Millstone Grit, 500 feet, without coal seams; Carboniferous Limestone, 2,000 feet, limestone, volcanic bed, coal seams, the Hurlet limestone at base; Calciferous Sandstone, divided into (1) Oil Shale Group, 4,000 feet, with 2 thin coals in upper part and oil shales in middle and lower parts; (2) Cement Stone group, without coal and resting on the Old Red Sandstone.

The great Carboniferous Limestone, thousands of feet thick in portions of England, is split up here into not more than a half dozen beds, each at most 50 feet thick, with sandstones, shales and coal seams in the intervals. There are many coals, almost 50, and at least 17 of them exceed 2 feet in thickness. One has maximum of 8 feet and another of almost 6 feet. These are thoroughly typical and rest on underclays with abundant *Stigmaria* in place. Ironstone, economically important, occurs at many horizons. At Bridgeness in the Bo'ness area, Cadell more than once explored an old forest exposed by workings on the Craw Coal. On one occasion, he counted 113 stumps, *Sigillaria*, distributed along 400 yards of roadway. They were arranged in clumps and were from two and one half inches to two and one half feet in diameter. The stems in great proportion were prostrate. Cadell conceives that they were broken off by a violent wind from the south, as most of them lie over toward the north. The vertical stumps were filled with ferruginous mud and the bark remained as coal. One of the sandstones is ripple-marked, has casts of fresh-water shells and flattened heaps of worm-castings.

Two thin coals, Two-feet and Houston, are about 1,000 feet below the Hurlet limestone; they are true coal seams but are very high in ash. The Houston, at one place, is 5 feet 9 inches in 4 benches, including a 2-inch cannel, directly under the top bench; at another, it is somewhat more than 11 feet and has a bench of oil shale. The coal is soft, but at its best is pyritous and dirty.

The notable feature of the group is the Oil Shales, which is easily recognized. It gives a brown streak, is tough, resists the weather and is not gritty. The thickness varies; at times a deposit disappears or passes into ordinary shale; at others, it may reach 15

feet, including partings of ordinary clay. It is finely laminated, but this feature is distinct usually only in "spent clay," that which has been treated. Thin streaks have been discovered in shales within the Carboniferous Limestone, but they are unimportant. Four important horizons are in the Calciferous Sandstone, the chief one being at 3,200 feet below the Limestone base. At some places, the shale has many impressions of fish; at others it is composed almost wholly of minute cyprids and crustaceans, so abundant that the shale resembles fine linseed cake. With these are fragments of ferns. The lagoon of deposit had an area of not less than 330 square miles. The best shale has fixed carbon, 5; volatile, 25; ash, 70 per cent. A yield of 30 gallons of oil per ton is that of good shale.

The Craigleith Sandstone, at base of the Calciferous, is well marked in the Edinburgh area, whence Witham obtained his tree, which, evidently, was a "snag." Brown[114] described this sandstone as made up of lenses, thinning out in all directions and dovetailing. Coaly laminations, derived from drifted material, are numerous. The water was shallow; sun-cracks, worm tracks, ripple-marks, rainprints and footprints of labyrinthodonts have been observed. Brown found in the quarry a large block of current-bedded sandstone containing several casts of *Lepidodendron*. The largest fragment, 3 feet long and 14 inches wide, was somewhat compressed and retained some of its bark, converted into coal. At one side in the interior was a thick layer of brown material, but the rest of the cavity was filled with sand. The brown substance contained numbers of the gasterpod, *Platyostomella,* and the "nests" were formed before the sand was deposited, for the laminæ of the latter curve around them. This gasteropod was probably an estuarine form. At another locality, it is associated with *Spirorbis pusillus,* which may indicate marine conditions. At the same time, the Craighill species has peculiarities, which lead Brown to suggest that, like *Hydrobia,* the genus may have had fresh-, brackish- and salt-water species. The question of adjustibility of molluscs to changing marine or fresh-water conditions is unimportant. They can and do

[114] C. Brown, "On the occurrence of Gasteropods (*Platyostomella scotoburgalensis*) in a *Lepidodendron* from Craighill Quarry, Edinburgh," *Trans. Edinb. Geol. Soc.,* Vol. VII., 1897, pp. 244–251.

adjust themselves. De la Beche[115] states that *Voluta magnifica* lives high up in brackish water near Port Jackson, Australia, and that an *Arca* inhabits the fresh-water of Jumna River at 1,000 miles from the sea. G. B. Sowerby had informed him that an *Astarte* and a *Cardita* had been found in pools on the ice near Melville Island, and that a *Nucula* lives in the Ganges at Banda. An *Anodon* thrives in brackish water at the Commercial Docks of London, where it is associated with a *Mytilus* brought from the Danube. He cites McCulloch, whose experiments proved that many marine fish and crustaceans can become habituated even in fresh-water. Almost 80 years ago, J. W. Bailey discovered a strange commingling of fresh-water and marine types in the Hudson River near West Point, where one reaches practically the limit of brackish water.

South America.

Brazil.—Permo-Carboniferous rocks have been reported from several countries in South America and have been described in admirable memoirs; but such deposits are most important in Brazil, where, according to Branner,[116] "the Permian is, *par excellence,* the Brazilian series." They were recognized by Eschwege in 1832 and, since that time, they have been studied in the several states by many geologists, among them, F. de Castelnau, O. A. Derby, C. F. Hartt, Oliveira, P. W. Lund and M. A. R. Lisboa. For the most part, the examinations were reconnaissances, sufficing to prove extent of the deposits, but giving detailed information respecting few areas. Whether or not the Coal Measures are present remains to be determined. The Permo-Carboniferous has coal in the southernmost states.

Hartt[117] states that Perigot discovered the coalfields of southern Brazil in 1841. A detailed study of the deposits in Santa Catharina was made by U. Plant, whose report, made in 1869, was republished by Hartt. On the Rio Candiota, Plant found, in a section of 70

[115] H. T. de la Beche, "Researches in Theoretical Geology," Amer. ed., N. Y., 1837, pp. 224, 225.

[116] J. C. Branner, "Outlines of the Geology of Brazil," *Bull. Geol. Soc. Amer.*, Vol. 30, 1919, pp. 211.

[117] C. F. Hartt, "Geology and Physical Georgraphy of Brazil," Boston, 1870, pp. 519–531.

feet, 56 feet of coal in four seams, 3, 11, 17 and 25 feet. Coal from the 17-feet seam was tested by steamers on the Rio Grande with good results, though the ash is high. The coal is caking and yields from 6,700 to 8,198 cubic feet of gas with 5 to 5.8 candle-power.

Almost two score years later, White[118] examined the coal areas of Rio Grande do Sul, Santa Catharina, Paraná and São Paulo, the southern state of Brazil. His conclusions did not justify hopes based on reports by earlier observers. The deposits were laid down on an irregular surface of granite, which, at times, is within a few feet of the lowest coal, at others, separated from it by a considerable thickness of rock. The succession, near Minas in Santa Catharina, is: Santa Catharina System, composed of São Bento Series, 900 meters; Passa Dois Series, 228 meters; Tubarão Series, 280 meters. The São Bento Series, red sandstone and shales, is capped by a great thickness of eruptive rocks and is assigned to the Triassic. The Passa Dois Series, shales with thin limestone at top, is without coal and is referred by D. White to the Damuda series of India. The Rio Bonito sandstones and shales of the Tubarão Series, containing the coals, are 158 meters thick near Minas and have 5 coals; at one place in São Paulo, 170 meters and no coal; at one in Paraná, 270 meters and no coal; at one in Rio Grande do Sul, the group is but 57 meters with one thick and four thin coals; while at 18 kilometers farther south it is 145 meters with one thick and 13 thin coals. In the greater part of the region, the Rio Bonito consists chiefly of yellowish to grayish white feldspathic sandstones, which are poorly consolidated; in much of Rio Grande do Sul, however, shale predominates.

The coals were seen first in Santa Catharina, where, near Minas, 5 seams were examined, Treviso, Barro Branco, Irapuá, Ponte Alta and at bottom, Bonito; but at 60 miles northward, only one seam, probably Barro Branco, was seen. In the northern states, Paraná and São Paulo, the distribution of coal is indefinite; at best the seams are very thin and they are wanting in many districts. Even in Santa Catharina and Rio Grande do Sul, the seams are so irregular that they may be regarded as local, the only really persistent

[118] I. C. White, Commisão de Estudos de Carvão de Pedra do Brazil, Relatorio Final," Rio Janeiro, 1908, pp. 1–300.

horizon being the Barro Branco. Southwardly, the coal measures pass under cover not far south from Minas and come again to the surface near São Jeronymo in Rio Grande do Sul, where the Treviso is represented by shale, the Irapuá by shale and coal, but the Barro Branco or São Jeronymo is important. At Serro Partido near Rio Candiota, where Plant obtained his section, the section as measured by White is, thicknesses being given in meters, (1) shale, sandstone and concealed, 19.28; (2) coaly shale, 0.91; (3) shale with plants, 2.29; (4) coal and shale, 0.305; (5) clay, 1.52; (6) shales, dark and yellow, plants in latter, 1.04; (7) São Jeronymo Coal, 4.78, consisting of (*a*) slaty coal, with *Sigillaria* in roof, 1.22, (*b*) blue clay, 0.51, (*c*) carbonaceous shale, some coal, 1.22, (*d*) impure coal, 1.83; (8) clay and shale, 6.59; (9) interval in shaft, reported, 12.19; (10) Irapuá Coal, 0.20 to 0.36. It is evident that the earlier observer mistook dark shale for coal.

The one persistent coal horizon is the Barro Branco-São Jeronymo, but it varies greatly. It is usually triple in the Minas region, though more divided at times, the thickness varies from 0.93 to 2.20 meters, and the coal is described as "good" to "fairly good" and "slaty." In Rio Grande do Sul, it has, at one place, 2.68 thickness with a parting of clay, only 10 centimeters, but at other places this parting is from 3 to 5.30 meters. The other seams are traceable in the two southern states, but for the most part they are thin. The roof at most places is a leaf-bearing shale and the floor is clay or clay shale. One can hardly recognize faux-mur or faux-toit owing to character of the coal.

The coal is always high in ash and usually in sulphur. Analyses of that from the one important horizon show:

	Barro Branco.	São Jeronymo.
Moisture	1.01 to 1.21	3.43 to 6.05
Volatile	7.64 to 26.00	22.98 to 29.09
Fixed Carbon	35.34 to 54.63	37.52 to 44.20
Ash	24.88 to 28.38	23.04 to 31.17
Sulphur	1.58 to 11.42	0.60 to 12.96

The sulphur is present as pyrite and it, as well as a great part of the ash, can be removed by washing. Briquettes, made from washed coal, have from 8 to 14 per cent. of ash and 0.64 to 1.31 of

sulphur. The natural coal is inferior everywhere; evidently, the swamps, in which it was formed, were subject to frequent overflows of muddy water. There is no reason for believing that the sea invaded the region during the Permian.

D. White,[119] in the same volume, publishes an elaborate discussion of the plant remains and conditions. A shale in the Bonito Coal is crowded with megaspores, probably of *Sigillaria,* and a fine-grained flinty fireclay is filled with roots tentatively referred to *Vertebraria.* He found *Vertebraria* in the Barro Branco-São Jeronymo Coal as well as in shale near Minas and in roof of the Irapuá Coal. *Reinschia australis* Bert. and Ren., was observed in a fragment of boghead picked up on the coast. This material, he is convinced, is not from Brazil but was dropped from an Australian vessel carrying Kerosene Shale.

The roof of the Irapuá Coal contains *Glossopteris* and *Noeggerathopsis;* that of the São Jeronymo, at one locality, contains carbonized roots along with matted leaves of *Noeggerathopsis,* while, at another, it is an impure coal, whose dull layers are full of leaf and wood material in charcoal, and at a third, the dull layers consist largely of charcoal derived from *Lepidodendron, Sigillaria,* etc.

He finds Gondwana forms in the lowest portion of the coal measures. He is convinced that the Tubarão Series is practically equivalent to the Talchir-Kharhàrbari of India, Newcastle of New South Wales, Bowen of Queensland, etc. The Passa Dois Series is most probably equivalent to the Damuda Series.

[119] D. White, The same, pp. 337–607.

INDEX.

The references are to the lower pagination.

I. AUTHORS CITED.

Agnew, D., 66.
Aiton, W., 58.
Ames, J. W., 83.
v. Ammon, L., 53, 81, 86, 106, 159, 161, 382, 384, 385.
Anderson, 3.
Andersson, G., 7, 35.
v. Andrian, 191.
Anker, 174.
Arnauld, 186.
de Aspiroz, 418.
Atkinson, T. W., 10.
Atwood, W. W., 151.
Aveline, W. T., 290.

Bailey, J. W., 436.
Ball, V., 342, 344.
Ball, M. W., 208, 214, 233.
Barrois, C., 398, 401, 404, 405, 415-418.
Barrow, G., 289.
Beekly, A. L., 143, 213, 234, 252.
Berry, E. W., 44, 62, 106.
Bertrand, C. Eg., 413, 414.
Bertrand, P., 398, 404, 405.
Berzelius, 83.
Beyrich, 47, 192.
Beyschlag, 330.
Billingsley, 75.
Blanford, W. T., 12, 342, 343, 347.
Blytt, 35.
Bolton, H., 426, 428.
Boulay, Abbe, 404.
Bowen, C. T., 140, 210, 239.
Branner, J. C., 436.
Bredlick, W., 157.
Breton, L., 399, 403.
Brongniart, A., 3, 14, 89.
Brongniart, Al., 102, 408.
Brown, C., 435.
Brown, C. B., 4.
Brown, H. Y. L., 195.
Brown, R., 107, 154.
Buckland, W., 286.
Bunbury, C. J. F., 36.

Cadell, H. M., 433-435.
Calvert, W. R., 201, 210, 211, 217, 237, 238, 239, 254.
Cameron, 4.
Campbell, 258.
Campbell, M. R., 246.
Campbell, W. D., 197.
Camsell, C., 147.
Cantrill, I. C., 420.
Capps, S. R., 8, 97, 180.
Carnot, 152, 412.
Carpenter, F. G., 12.
Caspary, R., 18, 22, 24, 25.
Casselmann, 157.
Castelnau, F. de, 436.
Chevalier, A., 57.
Cochrane, J. D., 9, 10.
Clarke, W. B., 337.
Clifford, W., 315.
Colenso, J. W., 64, 171.
Collett, J., 45, 104, 145, 151, 171, 179, 300, 320.
Com. Geol. Russia, 10, 152, 298, 348.
Conybeare, W. D., 133, 290.
Conwentz, 155.
Cook, G. H., 31, 61.
Cornet, F. L., 396.
Cornet, J., 79, 393, 395.
Cox, S. H., 197, 261.
Credner, Hein., 187, 187, 190.

Credner, Herm., 48, 119, 170, 307.
Croll, J., 72.
Cromarty, Earl of, 28.
Cross, W., 205, 224.
Cžjžek, J., 192, 193, 260, 278, 292.

Dachnowski, A., 28, 30, 45, 77, 82, 83.
Dall, W. H., 148, 154, 168, 181.
Dana, J. D., 164.
Dannenberg, A., 354, 356, 360, 367, 369, 373, 374, 377, 381, 382, 384, 385, 387, 389, 392, 393, 394, 397.
Darton, N. H., 202, 203, 209, 217, 234, 236, 252.
Darwin, C., 36, 66, 89, 90, 171.
Dathe, E., 362.
Daubree, A., 110, 154, 177.
David, T. W. E., 187, 336, 338, 339, 340.
Davis, C. A., 14, 22, 26, 32, 43, 56, 61, 62, 77, 81, 82, 85, 96. 124.
Dawson, G. M., 148, 211, 240, 243, 252.
Debray, L., 30, 38.
Deicke, J. C., 51.
De la Beche, H. T., 34, 37, 95, 286, 422, 423, 436.
De la Harpe, Ph.. 47.
Demel, W., 76, 78, 153.
Denniston, R., 197, 258.
Derby, O. A., 436.
De Serres, 129, 130.
Doppler, 73.
Dowling, D. B., 147, 202, 211, 212, 241, 242, 243, 255, 256, 259, 262, 267.
Dubois, N., 160.
Dumble, E. T., 133, 318.
Dunker, W., 187, 188, 189, 257, 259.
Dunlop, R., 46.

Eldridge, G. H., 150, 179, 205, 217.
Emmons, E., 317.
Emmons, S. F., 205.
Erdmann, E., 305
Etheridge, R. E., Jr., 194, 196, 301, 334.
Evans, G. W., 145, 146, 175, 178.

Fairchild, H. L., 77.
Fayol, H., 410–413.
Featherstonhaugh, G. W., 328.
Fennemann, N. M., 209, 217, 219, 233.
Fiebelkorn, M., 121, 123.
Fisher, C. A., 253, 255.
Fontaine, W. M., 311, 312, 315, 332.
Forchhammer, G., 39, 42, 93.
Foster, W., 77, 78.
Fournet, J., 109, 174, 177.
Fox-Strangways, C., 289.
Frankenfield, H. C., 65.
Frazer, P., 111.
Fritsch, 373.
Früh, J, J., 24, 25, 76.

Gaebler, 354, 358.
Gale, H. S., 209, 213, 233.
Gardner, J. H., 207, 213, 220, 223, 224, 245.
Geikie, A., 27, 32, 72, 305.
Geikie, J., 34, 35, 40, 43, 56, 58, 72, 109.
Geinitz, F. E., 24, 42, 62.
Geinitz, H. B., 374, 376.
Gilbert, G. K., 222, 225, 245, 247, 248.
Gibson, W., 420, 425.
Glockner, F., 152, 182.
Goeppert, H. R., 41, 93, 356, 357, 360, 363.
Goldthwait, J. W., 45.
Gosselet, 419.
Gothan, W., 128, 174, 179, 297, 331.
Graefe, 84, 156.
Grand'Eury, C., 35, 113, 115, 172, 178, 281, 291, 295, 307, 331, 378, 405, 409.
Green, A. H., 429–433.
Gregory, A. C., 302.
Gregory, H. E., 246.
Griesbach, C. L., 345.
Gruner, L., 405, 406, 408.
v. Gümbel, C. W., 17, 22, 29, 38, 39, 40, 52, 72, 74, 104, 114, 123, 129, 131, 152, 156, 174, 182, 279, 293, 308.
Gutbier, 376.

Haast, J., 105, 198.

Haidinger, W., 17, 73, 132, 182.
Hall, J., 202.
Hance, J. H., 210.
Hantken, M., 105, 115, 116, 158, 162, 193, 294, 310, 320, 366.
Harper, R. M., 4, 11, 26, 88.
Harris, G. D., 64.
Harris, W. C., 70.
Harrison, 88.
Harrison, J. F., 4.
Hartig, 32.
Hartt, C. F., 4.
Hauchecorne, 47.
Hausse, R., 374, 376.
Hayden, F. V., 203.
Hebert, E., 305.
Hector, J., 196, 258, 261.
Heer, O., 19, 35, 49, 107, 132, 199.
Heinrich, O. J., 316.
Henshaw, F. F., 151.
Henslow, 330.
Herald, F. A., 140, 210.
Hermance, 153.
Herndon, J. H., 134.
Herrick, C. L., 221, 244.
Hertle, L., 292, 308, 329.
Herz, J. W., 75, 78.
Heusler, C., 125, 127, 176, 178.
Hilgard, E. W., 63, 88.
Hoffmann, G. C., 101.
Hörich, O., 128, 174, 179.
Horner, L., 124, 129, 176.
Horton, A. H., 70.
Hosius, 191.
Howell, E. E., 247.
Hughes, T., 342.
Hughes, T. W. H., 345.
Hull, E., 290, 419, 424, 427, 428.
Hunefeld, 83.
Hutton, F. W., 105, 131, 154, 158, 198, 261.

Jack, R. L., 194, 260, 301, 320, 334.
Jackson, H. J., 70.
Jameson, R., 3.
Jeffrey, E. C., 25, 78, 415.
Jentzsch, A., 24, 40, 42, 29, 93.
Johnson, D. W., 31, 61, 220, 221, 244.
Jones, E. A., 346.
Judd, J. W., 290.
Jukes, J. B., 420, 423, 424, 425.

Karsten, H., 154, 155.
Katz, F. J., 151.
Katzer, F., 113, 114, 115, 161, 163, 174, 370, 371, 372, 373.
Kaufmann, F. J., 74, 75, 76, 78, 153.
Keilhack, H., 47, 48.
Kendall, P. F., 290, 431, 432.
Kennedy, W. H., 134.
Kerr, W. C., 318.
Keyserling, H. G., 310.
Kidston, R., 420, 423, 425.
Kinahan, 77.
Kingsley, Miss, 4.
Kjellmark, K., 33.
Klaproth, M. H., 22.
Klebs, R., 52.
Kliver, 385.
Koorders, 4, 5, 6, 14, 37, 88.
Knight, W. C., 65, 208, 250.
Knowlton, 202, 205.
Kramer, G., 84, 156.
Kukuk, P., 112, 177.
Kuntze, O., 4, 88.

Lampadius, W. A., 19, 85.
Lapparent, de, 391.
Larive, 4.
Laspeyres, H., 118.
Lee, W. T., 200, 205, 213, 214, 219, 220, 223, 226, 229, 244, 248, 249, 252, 266, 278.
Leonard, A. G., 141, 166.
Lesquereux, L., 32, 35, 37, 38, 40, 62, 93, 95, 280.
Leverett, F., 45.
Lewis, F. J., 30, 32, 35.
Lewis, H. C., 45, 77.
Lindstrom, G., 305.
Lipold, M. V., 292, 305, 308, 310, 331, 371.
Liversidge, A., 338.
Livingstone, D., 3, 4.

Loutougin, L., 351.
Lorenz, J. R., 53.
Lorié, J., 11, 29, 43, 60, 71.
Lugard, 4.
Lupton, C. T., 225, 229, 248, 249, 266.
Lyell, C., 4, 12, 31, 55, 88, 186, 287, 312, 315.

Machielson, W. J. M., 6.
Mackenzie, J., 335.
McConnell, R. G., 150, 212, 242, 243.
McCoy, 337.
McCreath, A. S., 160, 311.
McAvoy, J., 242, 256.
McGee, W J, 45.
McKay, A., 198.
Mackenzie, J. D., 256.
McLearn, F. H., 242, 256.
Malloch, G. S., 256.
Mantell, G. A., 185, 186, 286.
Martin, G. C., 151.
Medlicott, H. B., 67, 347.
Medlicott, J. G., 347.
Meek, F. B., 202, 203.
Meugy, 186
Mietsch, H., 374.
Michael, R., 354.
Miller, H., 28, 288, 321.
Miller, W. G., 65, 66.
Mills, E. G., 79, 80, 83.
Molengraaff, G. A. F., 5, 6, 14, 49, 88, 130, 194.
Morris, J., 288.
Mouchet, 109.
Mourlon, M., 392.
Muhlberg, 75, 76.
Mulder, G. J., 80, 83.
Munier-Chalmas, 391.
Murchison, R. I., 174, 287, 291, 350, 353, 376, 380, 419.

Nasse, R., 382, 383, 384.
Nathorst, A. G., 7, 108, 298, 305, 332, 353.
Naumann, C. F., 120.
Nehring, A., 48.
Nendtwich, C. M., 114, 116, 161, 162, 323.
Newberry, J. S., 45, 67, 238, 255.
Nikitin, S., 350.
Nilson, 40, 93.
Nordenskiold, A. E., 10, 68.

Olry, 398.
Ordnance Survey, 59.
Ormiston, G. E., 67.
Orton, E., Sr., 45.

Palliardi, 19.
Pardee, J. T., 107, 159.
Peake, Major, 15.
Penck, A., 119, 178, 179.
Pengelly, W., 132.
Penrose, R. A. F., Jr., 85, 134.
Pepperberg, L. J., 239.
Percy, 160.
Petrascheck, W., 356, 358, 359, 360.
Pfeiffer, I., 6.
Phillips, J., 44, 287, 288, 290.
Phillips, W. B., 135, 163.
Plant, U., 436, 438.
Plettner, 116, 163.
Pokorny, A., 21.
Pollard, W., 423.
Poole, G. S., 33.
Potonié, H., 5, 18, 21, 37, 48, 60, 91, 95, 111, 112, 121, 122, 154, 156, 176, 177, 179.
Purkyné, C. R. v., 368.
Purves, J. C., 391.

Rachoy, J., 292, 293, 309, 326.
Raefler, F., 122, 156, 170.
Ramsay, A. C., 290, 424.
Rashleigh, P., 65.
Rands, W. H., 302, 303.
Reade, T. M., 69.
Regnault, 187, 259, 324, 412.
Reid, C., 46.
Reinsch, 25, 188, 344.
Renault, B., 44, 413, 414.
Renier, A., 391, 396, 397.
Reuss, A. E., 131, 178, 192.
Riebeck, 157.

Richardson, G. B., 137, 216, 225, 226, 247, 258.
Robert, 109.
Rogers, G. S., 140.
Rogers, W. B., 308, 324.
Rolland, M., 415.
Rose, B., 212.
de Rouville, P., 306.
Rowan, F. J., 79, 80, 83.
Russell, I. C., 8, 11, 67, 68, 287, 315, 317, 329.
Russell, R., 429–433.
Russwurm, P., 112, 175, 179.
Rutot, 43.
Rzehak, A., 281.

Sanford, 30.
v. Sandberger, F., 307
Sauerwein, 260.
Sawkins, J. G., 4, 108, 160.
Schmidt, 10.
Schmitz, G., 400, 401, 403.
Schrader, F. C., 222, 224.
Schreiber, H., 35, 54, 93.
Schrötter, 73, 76, 153, 193, 260.
Schuchert, C., 199.
Schultz, A. R., 208, 214, 231, 250.
Schwaner, C. A. L. M., 6.
Scrope, G. P., 290.
Scupin, H., 191.
Sedgwick, A., 174.
Sernander, R., 26, 33, 35.
de Serres, M., 291.
Servier, 305, 324.
Shaler, M. K., 207, 224.
Shaler, N. S., 4, 30, 61, 96, 312, 315.
Siebenthal, C. E., 234, 235.
Siegert, 153, 374, 377.
Sirodot, 44.
Skertchly, S. B. J., 12, 32, 33, 36, 38, 43, 59.
Smeysters, J., 392, 396, 402.
Smith, C. D., 141, 146.
Smith, E. E., 145, 168, 214, 232, 233, 257.
Smith, G. D., 145.
Smith, R. A., 82, 415.
Smith, W., 179.
Sorby, H. C., 433.
Sowerby, G. B., 436.
Spencer, A. C., 224.
Spilker, A., 84, 156.
Spring, W., 39
Stainier, X., 392, 393, 394, 396, 400, 402.
Stanton, F. M., 81, 82.
Stanton, T. W., 199, 202, 203, 230, 235, 250, 252.
Stebinger, E., 140, 201, 208, 211, 214, 217, 233, 240, 255, 265.
Steenstrup, 22, 35.
v. Sternbach, G., 292, 293.
Sterzel, J. T., 374, 377, 379.
Stevenson, A. E., 7.
Stevenson, J. J., 108, 205, 215, 216, 217, 220, 413.
Stinson, J. M., 77.
Stohr, E., 120, 121, 122, 179.
Stone, R. W., 201, 211, 217, 254, 318, 325.
Stopes, M. C., 430.
Strahan, A., 420, 422, 423.
Struckmann, C., 187, 189, 190.
Stur, 359.

Taff, J. A., 138, 165, 225, 230, 279.
Tait, C., 55, 58.
Taylor, F. B., 45.
Taylor, R. C., 312.
Tennison-Woods, J. E., 304.
Thiessen, R., 137, 144, 147, 154, 207, 257, 258, 279, 415.
Thomson, C. W., 63, 90.
Tiddeman, R. H., 420.
Toula, F., 104.
Travers, M. W., 179.
Travis, C. B., 43.
Tschernychew, T., 351.
Tyrrell, J. B., 9, 211, 212.

Vance, J. H., 140.
Van Nouhys, J. W., 7.
Varrentrapp, 187, 259.
Vaux, 164.

Veatch, A. C., 208, 214, 233, 246, 250, 251.
Vogt, C., 19.
Von Post, H., 18, 20, 25.
Von Post, L., 35, 60.

Wall, G., 4, 108, 160.
Washburne, C. W., 205, 216, 217, 236.
Watson, D. M. S., 430.
Weber, C., 48.
Webster, T., 185, 286.
Weed, W. H., 67, 238, 255.
Wegemann, C. H., 138, 165, 176, 208, 209, 217, 219, 230, 235, 249.
Weiss, 384, 385.
White, D., 135, 136, 142, 143, 147, 153, 172, 179, 182, 199, 206, 258, 280, 437, 439.
White, I. C., 437, 438.
Wichmann, C. E. A., 6, 7.
Wilkinson, C. S., 304, 329, 337.
Willcox, 15.
Willey, D. A., 15.
Willis, B., 145, 200.
Winchester, D. E., 209, 210, 217, 245.
Witham, 288, 321, 435.
Witt, 156.
Woodruff, E. G., 139, 165, 209, 210, 235, 236, 251.
Woodward, H. B., 33, 75.
Woodworth, J. B., 312.
Woolsey, L. H., 139.
Worrell, S. H., 135, 164.
Woskresenski, 80.
Wright, G. F., 15, 68.
Zincken, C., 32, 75, 80, 102, 122, 157, 163, 164, 260, 297, 309.
Z'rkel, F., 16, 102.

II. GENERAL INDEX.

Adaptability of mollusca, 436.
Adaptability of trees growing on peat, 96.
Age of coals in New South Wales, 337.
Algae, 16, 20, 25, 26, 124, 156; in peat, 19, 20; in boghead, 414, 415.
Algonkian, 200.
Alum coal, 127.
Amber, 154.
Analyses, Blätterkohle, 157, 158; Boghead, 414; Cannel, 258, 259, 320; Coal, Pliocene, 158; Miocene, 108, 109, 114, 160, 162; Oligocene, 162, 163; Eocene, 150, 164–169; Cretaceous (foreign), 187, 190, 193, 195, 260, 261; (American), 262–267; Jurassic, 320–324; Triassic, 311, 319, 324, 325; Paleozoic, 366, 374, 418, 478; Peat, 79–82, 86, 87; Dopplerite, 153; Pyropissite, 155, 157; Zittavite, 153.
Anthracite, in Eocene, 145, 146, 167; in Cretaceous, 264; in Jurassic, 299; in Triassic, 319; in Paleozoic, 351, 373, 389, 397, 415, 423.
Ash, in peat, 81; in Tertiary coal, 159, 165; Cretaceous, 187, 194, 241, 246, 248, 255, etc.; Jurassic, 326; Triassic, 309; Paleozoic, 343, 344, 345, 349, 370, 377, 407; analysis, 165.

Baggertorf (Specktorf), 17.
Bark resists decay, 36, 37.
Bastkohle, 102, 103.
Basins or fields, Aachen, 389; Andenne, 390; Angora River, 320; Appalachian, 227; Ashland, 356; Aurunga, 344; Autun, 415; Basse-Sambre, 390; Bighorn, 209; Big Sandy, 239; Black Mesa, 246; Black Tail, 229, 249;

Book Cliffs, 225; Bowen, 235; Boulder, 263; Bridger, 237; Buffalo, 209; Campine, 390; Canyon City, 205, 216, 263; Cerillos, 220, 244, 264; Charleroi, 390; Coalville, 230, 249; Colob, 247; Commentry, 410; Couchant-de-Mons, 395; Crowsnest, 224, 256; Culbertson, 141; Deer Creek, 246; Denver, 205; Dinant, 390; Döhlen, 374; Ebersdorf, 374; Erzgebirge, 374; Electric, 237; Emery, 248; Engle, 219; Grand Mesa, 226; Grande Bira, 320; Great Falls, 255; Green River, 208; Hagan, 220, 245; Hainaut, 390; Hainichen, 374; Harmony, 247; Herve, 390; Indebecken, 389; Jheria, 342; Kladno, 369; Lancashire, 426; les Ferrieres, 410; Liége, 390; Limbourg, 390; Lewistown, 239, 254; Loire, 405; Lothians, 433; Lost Spring, 209; Lower Loire, 405; Lower Silesian, 360; Löwenburg, 191; Lugau, 374; Merklin, 369; Miroschen, 369; Milk River, 239; Moose River, Mountain, 255, 256; Nagy-Kovacsier, 116; North Carolina and Virginia, 310; Northern, 433; North Staffordshire, 369; Pas-de-Calais, 404; Pegauds, 416; Pilsen, 368; Pinedale, 246; Radnitz, 369; Ramkola, 345; Rock Spring, 208, 214, 281; Ruhr, 386; Richmond, 312; Rio Puerco, 221, 245; Saarbrück, 381; St. Etienne, 405; San Juan, 207; Sierra Blanca, 219; South Staffordshire, 433; South Wales, 420; Sussex, 217, 235; Tcheremkhovo, 320; Teton, 255; Tijeras, 221, 245; Trinidad-Raton, 205, 214, 263; Uinta, 207; Upper Amur, 299; Upper Silesian, 350; Valenciennes, 398; Vernal, 249; Wardha, 345; Würmrevier, 389; Yampa, 234; Yorkshire, 429; Zwickau, 374.

Bears Muck, 60.

Bechantite, 155.

Benches of peat deposits vary in composition, 29, 31; so in coal, 379.

Bernstein (Amber), 154, 192.

Bitumen from pyropissite, 156, 157.

Bituminous coal in Eocene, 146.

Bituminöse Holz, 106, 117, 119.

Black Band, 321, 426.

Black Hills, 203, 209, 217, 235.

Blätterkohle, in Tertiary, 102, 103, 126, 127, 157; in Cretaceous, 187, 259, 283; in Paleozoic, 357, 358.

Blättertorf (Papiertorf), 17.

Bleichflussigkeit, 52.

Boghead, 23, 298, 299, 320, 350, 411, 413; origin of, 414, 415.

Bog Meadows, 18.

Bowlders in peat, 46; in disintegrated granite, 316.

"Brand," 295, 366.

Brandschiefer, 188, 357, 370, 371, 376.

Breccia in Rothliegende, 419.

Briquets, 112, 117, 126, 128.

Brora, coal in Great Oölite, 287.

Brown (Tertiary) coal; contains no wood, 116; has woody structure, 114, 116, 132, 134, 140; contains erect stems and trees, 111, 120, 125, 127, 147, 150; leaf impressions, 117; layer of ferns, 133; swamp plants, 134; petrified wood, 130, 134, 135, 175; masses of wood, 134, 143; hollow stems, 112; composed of timber, 105, 141; mineral charcoal, 111; freshwater shells, 109,

110, 130, 131; insects, 110; vertebrates, 126; has lenses of canneloid coal, 135, 136, 146; which seem to be of Lebertorf origin, 150; is a complex group, 104.

Brown coal deposits; conditions during formation, 143; are variable, 105; names refer to horizons, not seams, 139, 140; freshwater origin, 105; of swamp origin, 105, 119, 129, 132, 150; are lenticular, 117, 119, 121, 122, 134, 135, 139, 141, 151, 152; resemble peat deposits, 105, 107, 143, 145, 159, 161; contain masses of quartz, 111; quartz sand, 117; Roof; variable, 115; has marine shells, 116, 131; has land plants, 106, 107, 132; has erect trees and stumps, rooted, 112, 120, 136, 147; is freshwater limestone, 137; is a dolomitic conglomerate; Floor, variable, 115, 121; contains no roots, 114; contains roots, 108, 121, 133, 135, 136, 142, 144; has rooted trees, 111, 112, 120; has freshwater shells, 110, 132, 137; Partings, 105, 112, 116, 118, 175; have land shells, 115; freshwater shells, 115, 116; plant impressions, 149; roots, 136; Faux-toit, 114, 120, 135, 136, 139, 142; Faux-mur, 110, 134, 139, 149.

Brown coal in Wealden, 186–188.

Bruchtorf, 54.

Buchow, brown coal of, 118.

" Bullions," 420, 430.

Buried forests in peat, 13–34; of Bombay Island, 67.

Burrum coals, 323.

Cane-brakes act as filters, 32.

Cannel, 349, 354, 364, 368, 372, 388, 394, 422, 425, 427, 430, 434; is in lenses, 341; contains Stigmaria, 370, 427.

Canneloid coal, Tertiary, 136, 146 158; Cretaceous, 197, 247, 248, 253, 254, 258, 259, 282; Jurassic, 301; is in lenses, 303, 320.

Carbohumin, 52, 99.

Carse area, buried peats of, 43.

Caustic potash, 75.

Clay with tree stems, 306.

Climbing bogs on granite, 56.

Coal; defined, 101; classification, 396–399; distribution of, 268–272; different types in a vertical section, 259; has woody structure, 294; contains silicified wood 206; plants, 306, 307, 331, 339, 358, 364, 365, 407; jetified wood, 206; Spores and pollen exines, 207, 308; scales and teeth, 315, 424; resins, 206, 340, 365; coarse, 314; peat-like, 330; mineral charcoal, 206; pebbles of rock, 195, 197, 306, 359, 395; caking coal in Eocene, 146, in Cretaceous, 264, 267 in Jurassic, 293, 294, 299, 303, in Triassic, 309, 313, 320; composition not always indicated by structure, 163.

Coal deposits tend to decrease in direction of finer sediments, 189, 190; are inconstant, local or lenticular, 205, 209, 210, 212, 215, 218, 226, 228, 232, 233, 236, 238, 239, 240, 253, 275, 276, 283, 296, 309, 310, 314, 338, 342, 343, 349, 351, 352, 355, 361, 362, 366, 367, 370, 384, 388, 395, 407, 410, 415, 421, 422, 425, 427, 429; poor coal on borders of lenses, 209, 302; seams vary, 226, 237, 296, 302, 303, 313; are replaced with shale or sandstone, 188, 232, 345,

347, 351, 399; with blackband, 367; with dolomite, 396; bifurcate, 206, 207, 215, 229, 309, 313, 337, 338, 343, 350, 356, 358, 375, 376, 402, 415, 424, 425, 428, 429; are distorted by pressure, 293; coal varies in the several benches, 193, 197, 206, 228, 295, 331, 338, 341, 357, 397, 406, 424, 430; Faux-toit, 188, 193, 278, 297, 330, 338, 371, 415, 417, 430; Faux-mur, 206, 278, 295, 297, 299, 330, 358, 370, 373, 395, 412, 430; has plant remains, 370, 430; Roof (toit), its variations, 198, 232, 277, 292, 300, 313, 329, 330, 383, 421; marine, 196, 198, 217, 231, 247, 248, 287, 296, 328, 352, 359, 388, 389, 390, 392, 394, 405, 418, 430; has plant impressions, 309, 312, 338, 348, 358, 364, 399, 341, 412, 417; has Stigmaria, 378, 400; has Vertebraria, 439; contains erect stems, 337, 340, 359, 364, 379, 400, 403, 404, 408, 428, 424; fish remains, 364; pebbles, 401; Floor (mur), its variations, 289, 293, 298, 305, 307, 335, 415, 417, 422; rolls in, 232, 249, 406, 425; marine fossils, 248, 296, 328; rich in swamp plants, 306; is a root bed, 206, 280, 281, 288, 289, 290, 295, 297, 307, 312, 337, 339, 340, 353, 359, 388, 394, 408, 412, 417, 430, 432, 434; roots in floor give rise to stems, 281,, 432; roots descend from the coal, 288, 408; contains pebbles, 401; Partings, variations, 188, 215, 225, 248, 278, 279, 292; have roots in place, 295; contain marine shells, 296, 328, 359; contain fresh-water shells, 248, 328, though roof and floor are marine, 248.

Conferventorf (Dy-gyttia, Lebertorf, Sapropelic mud), 17, 18.

Conglomerate with tree stems, 318.

Colnische umbra, 103.

Conifers as peatmakers, 14, 16; decay slowly, 37.

Contemporaneous erosion, 71, 96, 138, 147, 178, 216, 248, 257, 276, 300, 304, 309, 329, 339, 340, 386, 406, 407, 412, 429, 431, 432.

Cretaceous of North America, classification of, 202–204; locally conformable with Tertiary, 200, 209; rests at west on a peneplain, 200; unconformities in, 201.

Cycles in formation of peat deposits, 98.

Cypress swamps, 4, 21.

Dane's Hill root bed, 288.

Decay of wood in the tropics, 6, 36, 37.

Deciduous trees as peat makers, 14, 16.

Delta hypothesis, 410.

Diatomaceous earth, 16, 67, 106, 126; Diatomtorf, 24; diatoms in Tertiary coal, 175.

Differential subsidence, 201.

Dogger, erect stems in, 289.

Donatus mine, Torfdolomite of, 128.

Dopplerite (Pechtorf, Torfpechkohle), 17, 73, 74, 75, 77, 77, 79, 132.

Drifted leaves in hollow stems, 37.

Drifted organic remains, 171.

Drummond Lake, its sunken forest, 37.

Dunes overlying peat, 40.

Durability of stems, 62–64.

Dy-gyttia (Conferventorf, Lebertorf, Sapropel mud), 18.

Dytorf, or Dy-jord, 20, 22.
Dysodil, 102, 103, 129.

Effect of pressure on peat, 93.
En chapelet structure, 395.
Engmose, 18.
Eocene oil-shale, 131.
Eolian structure, 274.
Erdkohle, 102, 103, 113.
Erect canes, partly buried, 67.
Erect stems, in peat deposits, 33, 48, 62, 378; in Schieferkohle, 50, 51; project from brown coal into overlying rocks, 120; in Cretaceous, 186, 188, 195; in Jurassic, 286–291; in Triassic, 315; in Paleozoic, 357, 364, 366, 402–405, 409, 416, 423, 428, 434; rooted in coal, 339, 343.
Esskohle, 388.

Faeröe Islands, Miocene coal of, 109.
Falkenau gas coal resembles Lebertorf, 114.
Fasertorf or Torffaserkohle, 17.
Faulschlamm, 25.
Feinkohle, 173.
Felted structure of forest litter, 90.
Feuerkohle, 120, 123.
Filled channels, in buried swamps, 71; in contemporaneous rocks, 72; in Mesaverde, 229; in coal seams, 422.
Fine-grained deposits not proof of deep water, 393.
Fish remains in Dysodil, 129; in Triassic, 314; in coal, 424.
Flachmoor, 18.
Flexed shale, 386.
Flora, local variations at same horizon, 128; Tertiary, 177; Cretaceous, 187, 189, 191, 196, 199, 227; Jurassic, 288, 297, 298; Jura-Trias, 303, 332; Triassic, 316.
Fold and fault of l'Esperance, 413.
Footprints, 186, 435.
Forest, fossil, 172, 339, 380, 408.
Forest Marble, a shallow water deposit, 290.
Formkohle, 112, 118, 127, 173.
Formations; Avaize, 409; Andenne, 391; Allison, 242; Barakar, 341, 342, 344, 345; Bearpaw (Lewis), 236, 240, 243; Bear River, 250, 251; Belly River (Two Medicine, Virgelle), 240, 242; Benton, 219, 244, 249; Blue Gate (Ferron), 248; Bowen, 334; Bowie, 226; Brêche de la base, 406; Burrum, 303; Calciferous sandstone, 434; Carboniferous limestone, 434; Caroni, 108; Charleroi, 391; Chatelet, 391; Chokier, 391; Claggett, 218, 236, 238, 243; Cloverly, 252; Colgate, 210; Colorado, 236, 244; Craighill, 435; Culm, 353, 361, 374, 415; Czenitzer, 354; Dakota, 251; Damuda, 341, 347, 437; Dempsey, 306; Desert, 194; Dinantien, 387; Dunvegan, 243; Eagle, 218, 239; Edmonton (St. Mary, Lance, Laramie), 211, 212; Etruria, 436;

Ferron, 248, 252; Fettkohlen, 382; Flammekohlen, 382; Flénu, 391; Flines, 399; Flötzleeren, 387; Fox Hills, 203, 208, 213, 214, 215, 217, 234; Frontier, 250, 251; Ganister, 420; Gehrener, 381; Goldbauter, 381; Golonog, 354; Gondwana, 349; Great Oölite, 287; Greta, 336; Gympic, 334; Halesowen, 424; Halymenites (Trinidad), 215; Hawkesbury, 304; Holzer, 382; Horsethief (Lennep), 210, 217, 240; Hultschin, 382; Hygiene, 218; Ipswich, 302; Judith River, 218, 236, 238, 239; Kamti, 345; Karharbari, 344, 347; Karwin, 354; Keele, 456; Keuper, 306; Kimmeridge clay, 287; Kladno-Pilsen, 368; Kootenai, 252, 253; Kounovaer, 368; Kuseler, 380; Lanarkian, 420; Laramie, 200; Lebacher, 381; Lena, 416; Lettenkohle, 307; Lewis, 229; Lias, 291, 292; Lihnauer, 368; Livingston, 210, 238; Loslauer, 354; Lower Estuarine, 289, 290; Lower limestone, 350; Lower marine, 336; Lunzer, 308; Machadeva, 344; Mancos, 221, 230, 244, 249; Mansbacher, 381; Mazuk, 225; Mesaverde, 218, 220–226, 231, 234; Middle Estuarine, 289; Millstone Grit, 420; Morrison, 252; Moscow, 350; Mulden, 354; Namurien, 391; Newcastle, 336, 426; Nikolai, 354; Niobrara, 244; Oberhofer, 381; Oil shales, 434; Orzesch, 354; Ostrau, 354; Ottweiler, 361, 369, 382; Panchet, 341; Paonia, 226; Parkman, 238; Paskapoo, 212; Passa Dois, 437; Pendleside, 420; Pennant, 420; Petrzkowitz, 354; Pictured Cliffs, 213; Pierre, 218, 229, 234, 239, 240, 243; Pine Ridge, 234; Pontyfract, 429; Potzburg, 382; Poudingue houiller, 391; Punta de la Mesa, 221; Purbeck, 285, 286, 329; Radowenz, 361; Radstockian, 420; Rajmahal, 341; Rand, 355; Raniganj, 341; Raton, 214; Rawlins, 232; Rio Benito, 437; Rive-de-Gier, 406; Rolling Downs, 194; Rollins, 226; Rothliegende, 361, 366, 371, 376, 381, 419; Ruda, 354; Rybnik, 354; Saarbrück, 354, 362, 382, 384, 387; Santa Catharina, 437; St. Mary, 211, 240; São Bento, 437; Satterflötz, 351; St. Etienne, 406; St. Chamond, 406; Schwadowitz, 361; Schatzlar, 361; Schlaner, 368; Sohran, 354; Staffordshire, 420; Star, 334; Stephanian, 391, 405; Étage sterile, 406; Sudetic, 354, 361; Talchir, 341; Tambacher, 381; Teinitzer, 368; Tineo, 416; Tomago, 336, 338; Tres Hermanos, 245; Tuberão, 437; Two Medicine, 240; Upper Limestone, 350; Upper Marine, 336; Vermejo, 214; Virgelle, 240; Waldenburg, 354, 362, 369; Wengener, 308, 310; Westphalian, 391, 393, 420; Wiannamatta, 304; Yoredale, 420; Zechstein, 419.

Fossil plants retaining organic matter, 339, 358.

Fossilized roots, 198.

Fragments of coal in sedimentary rocks, 130, 172, 191, 195, 273,

Freshwater deposit followed by marine marls, 111.

Frozen coal, 151.

Fundamental matter of coal, 144, 413.

Fungi in brown coal, 136.

Fusain (Faserkohle, Mineral charcoal), 104, 186, 187, 192, 357, 365, 375, 399.

Gallet, 395.

Gedanite, 175.

Gemeine Braunkohle, 102, 103.

Glanzkohle, 103, 104.

Granite bosses penetrate a coal seam, 313.
Gravel in coal, 195.
Green shale, 352.
Grobkohle, 357.
Grünlandmoor, 8.

Hag region of Scotland, 41.
Haidetorf, 17.
Hatchettin, 188, 257.
Heather, 58.
Heaths, 19, 20.
Hochmoor or Heathermoor, 18, 61.
Hoermose, 18.
Holderness peat alternates with freshwater clays, 44.
Holland-Belgium-France peat, area, 44.
Hollow stems filled with sand, 37; in peat, 95.
Holztorf, 17.

Infra-aquatic moors, 21.
Insects in brown coal, 126.
Interruptions in growth of peat deposits, 13; of brown coal, 176.
Inverted stem of a plant, 412.
Ipswich cannel, 320.

Jet, 104, 143, 155.

Kauri gum, 85, 155.
Kerosene shale (Hartley mineral), 336, 337, 338; in lenses, 341; contains plant remains, 338.
Kimmeridge coal, 330.
Kincardine Moss, 55.
Kjaermose, 18.
Klondyke region, peat and muck of, 9.
Knabbenkohle, 173.
Knorpelkohle, 112, 117, 121.

Lack of mineral matter does not prevent growth of trees on peat, 28.
Lake marl, 91, 171.
Lakes, Loch Brown, buried trees in peat, 28; Bubbling, peat of, 56; Haarlem, draining of, 83; Ponchartrain, buried forest, 31.
Lauenberg, buried peat near, 47; Lausanne, the same, 47.
Lauser coal seam, 115.
Lebertorf, 18, 22–26, 48, 57, 91, 181, 282.
Lettenkohle, 307.
Lignitic coal, 101; in Lower Carboniferous, 350.
Local unconformity in Eocene, 138; in Cretaceous, 201; in Coal Measures, 416, 429.

Logs in peat deposits, 31.
Lyngmose, 18.

Malays, 6.
Mammalian remains, Yukon gravels, 105; Tertiary coal, 174.
Martörv, 39, 40.
Meertorf, 17.
Mineral charcoal (see Fusain), in peat, 38; in Schieferkohle, 54; in Tertiary coal, 104, 108, 111, 118, etc.; in Cretaceous, 192, 208, etc.; in Jurassic, 321; in pyropissite, 123.
Miocene coals, 101, 106–116.
Mollusks in brown coal, 126.
Moorkohle, 102, 103, 112, 113, 118, 192.
Mooskohle, 106.
Moostorf, 16.
Mud cracks, 140, 171.

Nadelkohle, 102, 103, 111.
New Madrid, cypresses killed by submergence near, 97.
Niedermoor, 18.
"Nips" in coal seams, 422.
Nitrogen in peat, 81.
No evident relation between ash and volatile in coal, 164.
Nodular coal, 343, 342, 355.

Oaks in peat, 59.
Oil coal, 303.
Ontario, natural reforestation in, 65.
Oligocene coals, 101, 116–130, 147.
Oölitic wood, 128.
Origin of pools on surface of peat, 26; of charcoal partings in peat, 32; of drift timber, 71.
Orogenic disturbance in Rocky Mt. region, 204.
Osterwalde, Blätterkohle, 188; section at, 190.
Overturned trees in peat, 176; in Schieferkohle, 50; in Tertiary coal, 176.

Papierkohle, 102, 103, 124.
Papiertorf (Blättertorf). 17.
Paraffin shale in Lias, 295.
Peat. 78; felted structure not due to kind of plant or to attrition, 90; composed of offal from conifers, 34; an attractive soil for many trees, 16, 61; oxidation of, 41; compressed, resembles brown coal, 48, 54; contains diatomaceous earth, 16; foreign substances, 93; fossils, 94; sedges, 34, 57, 89; plants forming, 35, 89; mosses present, 7, 89, but not essential, 13, 14, 87; resist decay, 36, 47; pollen in, 25, 27; erect stumps rooted in, 29, 45, 48, 60, 61; erect trees in, 46, 59, 61; forests in, 8, 11, 20, 31–34; overturned trees, 6, 27, 59; roots of plants, 42; stumpless places in, 93; chemistry of,

79–81; worthless in greatest part, 82; preservation of organic materials, 36; nitrogen in, 87; paraffin in, 84, 99; resins in, 83, 84; benches vary in composition, 90.

Peat deposits, extent of, 11, 12, 87; origin of great deposits, 12; interglacial, 45, 46; preservation of, 41, 97; modern may disappear, 42; plant invasions protect, 41; tropical, 3, 4, 5, 6; subtropical, 88; effect of drainage, 35, 42; buried, 42, 43, 45, 49; growth not always continuous, 13, 19; stages in growth, 19–22; final stage not same everywhere, 28; growth affected by climatic changes, 32, 35; forested bogs, 4, 5, 18, 95; bursting bogs, 55. Roof, variable, 61; contains erect stems, 62, 97; may be freshwater or marine, 96; marine, 43; Faux-toit, 62. Partings, mark interruptions in growth, 92; vary in thickness, 29; sometimes are of mineral charcoal, 92; are present in diluvial brown coals, 53, 54. Floor, often a faux-mur, 57; varies, 56, 94; usually organic, 19, 57; forest litter, 30; fine sand, 45; carbonaceous clay, 46; marl, 47, 50; marine, 43, 47, 56; contains roots, 64; rolls, 96.

Pebbles of coal in sedimentary rocks, 340, 360, 411, 417, 421.

Pechkohle, 102, 103, 104, 116, 118, 127, 131; in Schieferkohle, 52; in Cretaceous, 191, 192; in Paleozoic, 357, 375.

Pechtorf (Dopplerite), 17, 72.

Pegass, 4.

Permian, coal in, 367, 376, 381, 383; is conformable to Carboniferous, 352, 353, 367, 368, 382, 409; not conformable to Carboniferous, 361, 375, 377, 382, 419, 426, 427, 429.

Petrified forest, 318, 339, 380, 408; petrified wood, 118, 119, 121, 151, 152, 223, 235, 240, 253.

Places, Admiralty Island, 149; Airdrie, 46; Ajka, 193; Alcaddin, 253; Altwasser, 364; Amalek Harbor, 149; Ata, 199; Atch'nsk, 349; Aunby Cutting, 288; Aurillac, 316; Aussee, 73, 75; Autun, 413; Baker, 140; Baltic coast, 39, 40, 43; Banjaluka, 115; Barod, 194; Bartenstein, 22; Bath, 290; Basin, 237; Bayreuth, 308; Bell Sound, 7; Bentheim, 189; Billston, 428; Blairmore, 255, 256; Blea Wyke, 289; Bonn, 124; Borreby, 83; Bourges, 399; Bovey Tracey, 132, 164; Bowie, 228; Brennberg, 114, 193; Bridgness, 434; Brisbane, 302; Brook Point, 186; Brora, 287; Bruhl, 126; Brzescze, 360; Buchow, 118; Buckeburg, 168; Budweis, 113, 373; Cabezon, 223; Canyon City, 219; Cape Bohemian, 298; Carbon Junction, 207; Castle Valley, 225, 248; Caunette, 129; Charleroi, 400; Chrudim, 191; Chukch Peninsula, 10; Cloughton Wyke, 290; Coalville, 208, 230; Cordeville Valley, 310; Cologne, 124, 126; Cooktown, 195; Craig, 213; Croinville, 305; Cuba, 223; Decazeville, 316; Demarara, 4; Deutz, 126; Diester, 189, 190; Discovery Harbor, 107; Doliewen, 23; Doué, 415; Dourges, 165; Drumkelin Bog, 35; Dudley, 424; Dürnten, 50; Durango, 207, 225; Edgemont, 252; Eibenthal, 366; Ekibas-touz, 348; Evans, 217; Evanston, 208; Everglades, 11; Falisoles, 402; Fochteles, 60; Fort Wingate, 222; Frankfort a. O., 118; Freienwalde, 118; Friesdorf, 127; Fünfkirchen, 193, 295, 296, 323; Fürstenwalde, 117; Gallina, 223; Gallup, 222; Garland, 237; Gatun Lake, 12; Gemmelaincourt, 306, 307; Germanton, 318; Glendive, 142, 146;

Gosselius, 400; Grand'Bac, 403; Grand'Croix, 407; Granschutz, 121; Gresten, 292; Grossau, 293; Grottau, 113; Grossweil, 53, 81, 84; Grünbach, 192; Grüneberg, 117, 118; Guildorf, 308; Gustrow, 24; Hannover, 187, 189; Häring, 131; Hat Creek, 148; Heilengebeil, 52; Helmstadt, 259; Helvetihof, 41; High Whitby, 291; Hinterholz, 293; Horrem, 126; Howard, 303; Hoyt, 135; Hoxne, 46; Iceland, 109; Imbergtobal, 52; Ipswich, 302; Irkutsch, 349; Island of Chiloe, 66; Isle of Ely, 43; Isle of Wight, 185, 186; Jakabau 24; Josephfelde, 53; Königsberg, 52; Kirghiz Steppes, 348; Königshütte, 35; Krainsberg, 307; Kimmersdorf, 23; Kirshberg, 309; Kleinzell, 308; Klinge, 47; Klittsdorf, 191; Lac, 129; La Cavalarie, 292; La Marche, 306; Larzac, 291; Leakeville, 318; Lehigh, 144, 206; Lens, 404; Lester, 136; Liévin, 404; Lilienfeld, 308; Linz, 126; Longeroux, 410; Lubau, 366; Lund, 305; Madi Plateau, 5; Marshall, 206, 207; Matanuska, 151; Mauvaises Terres, 202; Minden, 189; Mita-Novak, 115; Monero, 225; Morschwyl, 50, 51; Myslowitz, 355; Nericke, 33; Neustadt, 190; Newcastle, 230, 339; Newport, 421; Norroy, 306; Nort, 415; North Park, 213; Nugsuak Peninsula, 199; Obburgen, 74; Ochtrup, 189; Oedenberg, 126; Oldenburg, 24; Orebkau, 112; Otago, 198; Ouspenskoïe, 350; Panama Canal, 12; Paonia, 229; Parey, 306; Patoot, 199; Pechgraben, 293; Pecs, 296; Penistone, 431; Petroszeny, 172; Piehl, 54; Planitz, 375; Port Hudson, 63; Price Canyon, 226; Prince Edward Island, 31; Purpesseln, 23; Radowenz, 363; Ramloesa, 305; Raton Plateau, 215; Rautengrun, 72; Ramsau, 308; Rehburg, 190; Rehgarten, 309; Resicza, 366; Richmond, 106; Rixhoft, 40; Rockdale, 135; Rock Springs, 232; Romain, 306; Rott, 126; Saljo-Tarjan, 115; Samson Valley, 390; San Mateo, 223; Sauforst, 123; Scarborough, 289; Schatzlar, 363; Schaumburg, 188; Schweinfurt, 308; Scranton, 77; Scuir of Eigg, 288; Seeland, 39; Senftenberg, 156; Sheffield, 434; Simerols, 186; Siwierz, 307; Skutsch, 192; Sonthofen, 52; Sopris, 215; Soudjenka, 349; Soultz-sous-Forêt, 110; Stinking Spring, 223; Sundance, 253; Sunnyside, 225; Süntel, 190; Szabolcs, 296; Szt. Ivan, 116; Taimur Land, 10; Talliancourt, 306; Tcheremkhovo, 299; Terry, 140; Teuchern, 121, 143; Timan, 352; Tomsk, 349; Trinidad Island, 108, 160; Trinidad, 215; Toowoomba, 303; Tour-du-Pin, 110; Ufford, 290; Unkel, 126; Unterwetzikon, 50; Utigsdorf, 192; Utweiler, 125; Utznach, 50, 80; Valier, 241; Vasas, 296; Vion, 110; Weissenfels, 123, 156; Whitby, 291; Whitewood, 431; Wigan, 427; Willow, 52; Wilton, 142, 156; Winton, 195; Wurzburg, 307; Würzen, 120; Ystad, 40; Zabrze, 355; Zagradia, 366; Zawada, 357; Zsil Valley, 116.

Plankton, 25.

Platterkohle, 372.

Pliocene coals, 101, 104–106.

Pocosons, 61.

Pollen, in peat, 24, 25, 27; in Schieferkohle, 50, 51; in Tertiary coal, 123, 137, 144, 147; in Cretaceous coal, 207.

Peneplain, pre-Cretaceous, 200, 201.

Pyropissite, 123, 140, 155, 156.

Rainprints, 435.
Rasenmoor, 18.
Rasentorf, 17, 72, 76.
Red Rocks, 352, 353, 363, 368, 383, 421, 424, 425, 426, 427, 429.
Reforestation, natural, 65.
Relations of Triassic and Permian, 305; of Permian and Carboniferous, 352, 353, 361, 367, 375, 377, 382, 409, 419, 426, 427, 429.
Resins, in peat, 99; in Tertiary coals, 107, 117, 118, 121, 125, 135, 136, 137, 139, 143, 144, 146, 147, 148, 149, 150, 154; in Secondary coals 193, 196–198, 215, 216, 223, 225, 229, 238, 239, 246, 248, 257, 280, 282, 321; in Paleozoic coals, 340, 365.
Resistance to erosion, 68.
Retinite, 107, 198.
Reynold's expedition, 203.
Riedtorf, 54.
Riesenkohle, 173.
Rippled surfaces, 108, 140, 171, 186, 251, 252, 257, 273, 289, 290, 327.
River floods and vegetation, 65, 69–71.
Rocks of Richmond coal area, 312.
Rocks between coal seams often consist of dove-tailing lenses, 171.
"Rock Faults" in coal (Washouts), 425, 431.
Rock streams of the Alleghenies, 66.
Rocky Mt. Revolution, 200, 201, 203.
Rohhumus, 11, 30, 56.
Ross-shire, forest killed by peat, 28.
"Rothe Bruche," 32.
Ruskinton Fen, Birch bark in, 38.
Russkohle, 103, 114, 121, 122, 375.

Sand dunes covering peat bogs, 92.
Sand pockets in peat, 94.
Sandsäcke, 121, 122.
Sandstone, with false- or with cross-bedding, 171, 194, 217, 221, 228, 229, 233, 238, 239, 240, 243, 245, 248, 249, 251, 252, 254, 273, 274, 289, 290, 304, 307, 327, 342, 345, 347, 395, 419, 421, 425, 428, 432, 435; with ripplied surface, 220, 239, 243, 245, 317, 343, 344, 347, 392, 419, 428, 432, 434, 435; Contains fragments of coal, 191, 194, 195, 340, 360, 411, 417, 421; petrified wood, 195, 198, 200, 211, 215, 273, 274, 289, 303, 307, 312, 319; casts of plant stems, 335, 359, 364, 365, 412, 416, 425.
Sapropel mud, 18, 282.
Schieferkohle, 49, 50, 53, 75.
Schiefertorf, 54.
Schmiedekohle, 388.
Schmierkohle, 103, 128.
Schramm, 358.
Schwarte, 371.
Schwelkohle, 103, 112, 119, 120, 128, 156.

Seaforth dock, marine deposit between peat beds, 43.
Sea-invasions, 292, 294, 328.
Sedges as peat makers, 14, 57, 89, 110.
Senegal copal, 85.
Senftenberg, Miocene coal of, 111.
Shallow water mollusks, 296.
Shifting of channel ways, 328.
Sklok, 359.
Skovmose, 18.
"Splits" of coal seams, 432.
Snags, 291.
Soils of vegetation, 63, 67, 148, 151, 171, 198, 243, 277, 286, 288, 291, 329, 330.
Solway moss, burst, 55.
Somme, inverted shrub in peat of, 38.
Sonnaz, Miocene coal of, 109.
South Marsh, buried forest in, 33; dopplerite of, 75.
Specktorf (Baggertorf), 17.
Sphagnum, its share in peat-making, 13, 14; can grow on moist sand, 28, 30; is indifferent to calcium carbonate, 28.
Spores, 123, 137, 144, 147.
Stantienite, 155.
Sterzel on formation of coal seams, 377.
Strathcluony, Big Moss of, 34.
Sub-bituminous coal, 101.
Succession of plant life in peat, 19; of forests in peat deposits, 20.
Succinite, 111.
Sudd is floating mat of sedges and grasses, 15, 89.
Suderöe, origin of coal at, 109.
Südliche Hauptsprung, 382, 386.
Sulphur in peat, 81; sulphates in brown coal, 113.
Suncracks, 186, 194, 428, 435.
Supra-aquatic moors (Hochmoors), 21.
Surface water, its effect on brown coal, 128.
Suturbrander is of conifer origin, 109.
Svampmose, 18.
Swamps, Cypress, 4; Dismal, 4, 27, 37, 56; Okefinokee, 56; streams in, 71; washed out, 191.

Taiga of Siberia, 11.
Tarnsjomoor overlies a forest bed, 60.
Taundorf brown coal, an ancient swamp, 119, 178.
Temperature of secondary importance in peat-making, 7.
Teredo in buried forest, 67.
Terre de Cologne, 102.
Terrouille, 393.
Texas brown coals, 133.
Thelotite, 414.

Timber dense at bottom of brown coal, 112.
Topeka, reforestation after river flood, 65.
Torfdolomite, 128.
Torferde, 17.
Torfpechkohle, 17, 74.
Torffaserkohle, 17, 29, 38, 92.
Tourbiéres basses, 18; hautes, 18.
Turpentine vessels in Pinites eiggensis, 288.
Tyonek, driftwood (?) near, 151.

Ultimate analysis gives little clue to actual composition of coal, 161, 162, 165, 169.
Vitrioltorf, 17.
Volatile in coal decreases with depth, 387, 397, 399, 418; with increasing disturbance, 352; increases with depth, 384; with increasing disturbance, 397.

Wachskohle, 102.
Waldmoor, 18.
Waldtorf, 120.
Waxes in peat, 99; in brown coal, 144.
Wiesenmoor, 18.
Willows protect stream banks from erosion, 15.
Woodstone, 198.
Worm borings, 216; tubes, 228.
Wurzen, trees rooted in brown coal project into overlying rock, 120.

Zittavite, 153.
Zwischenmoor, 18.